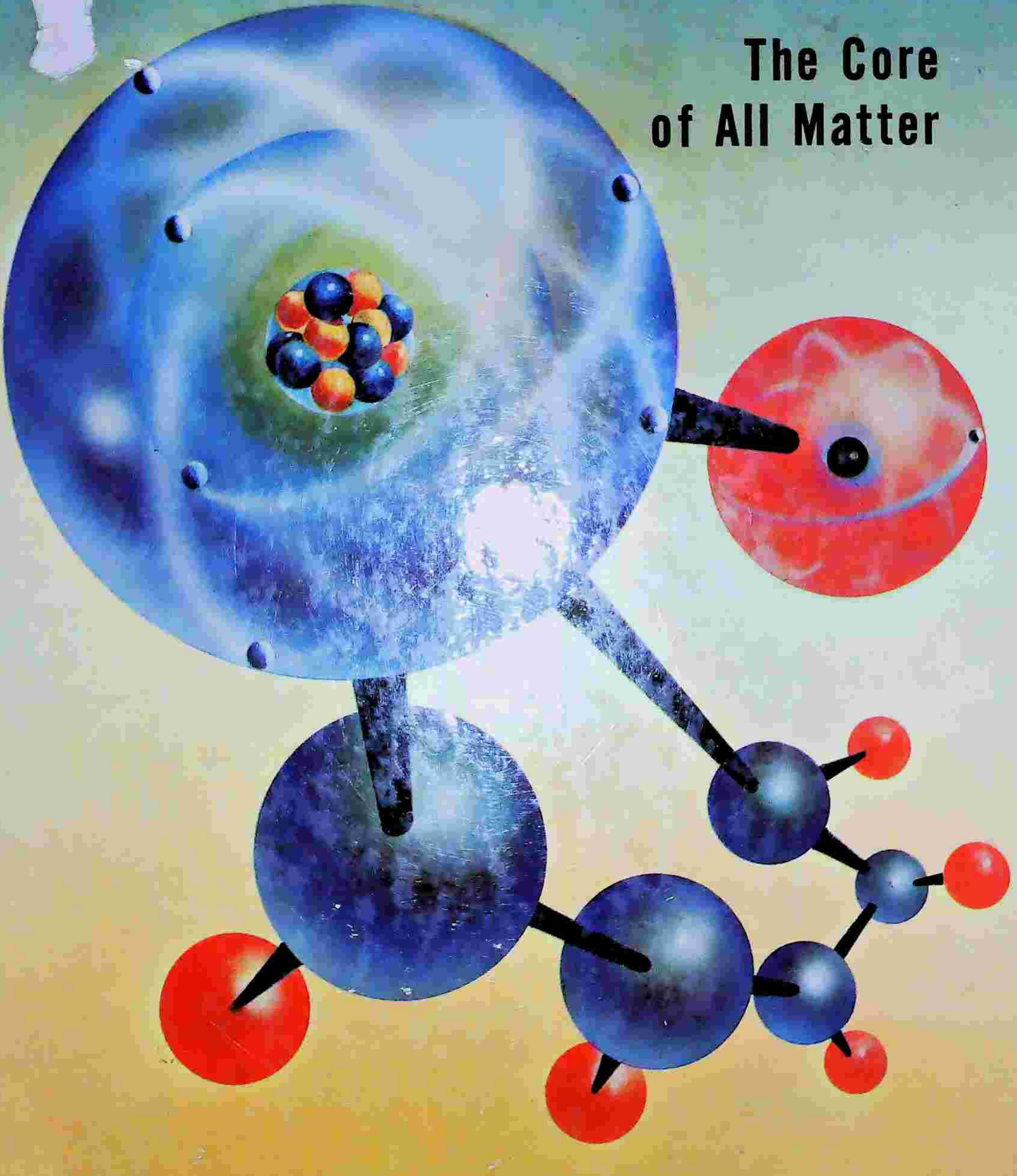
ATOMS

The Core of All Matter



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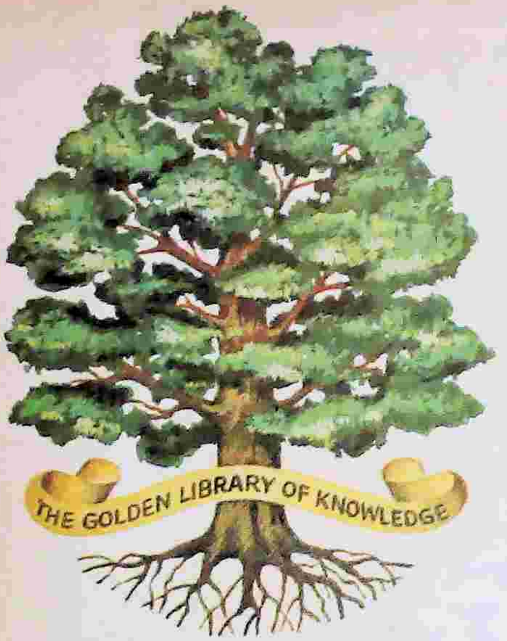
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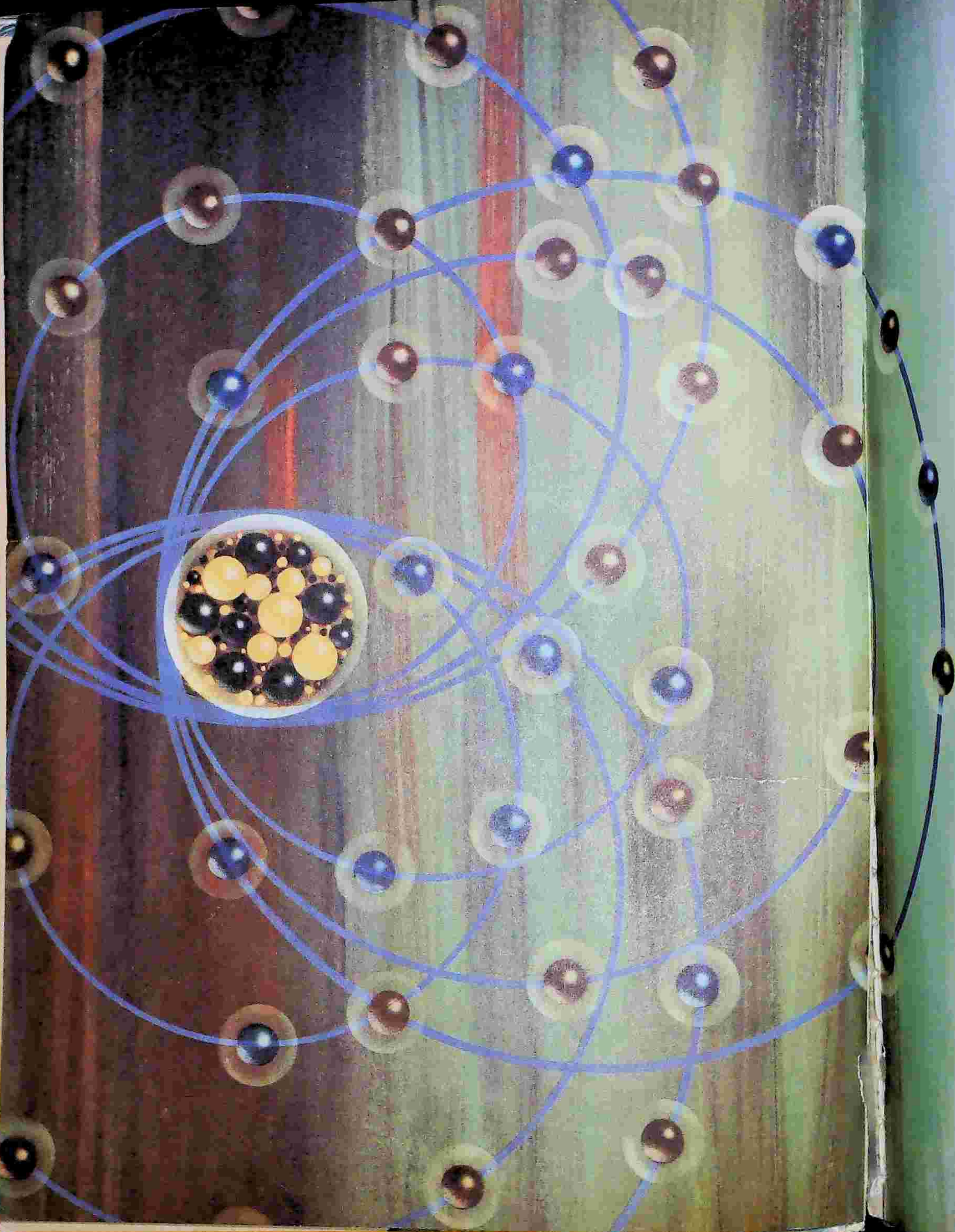

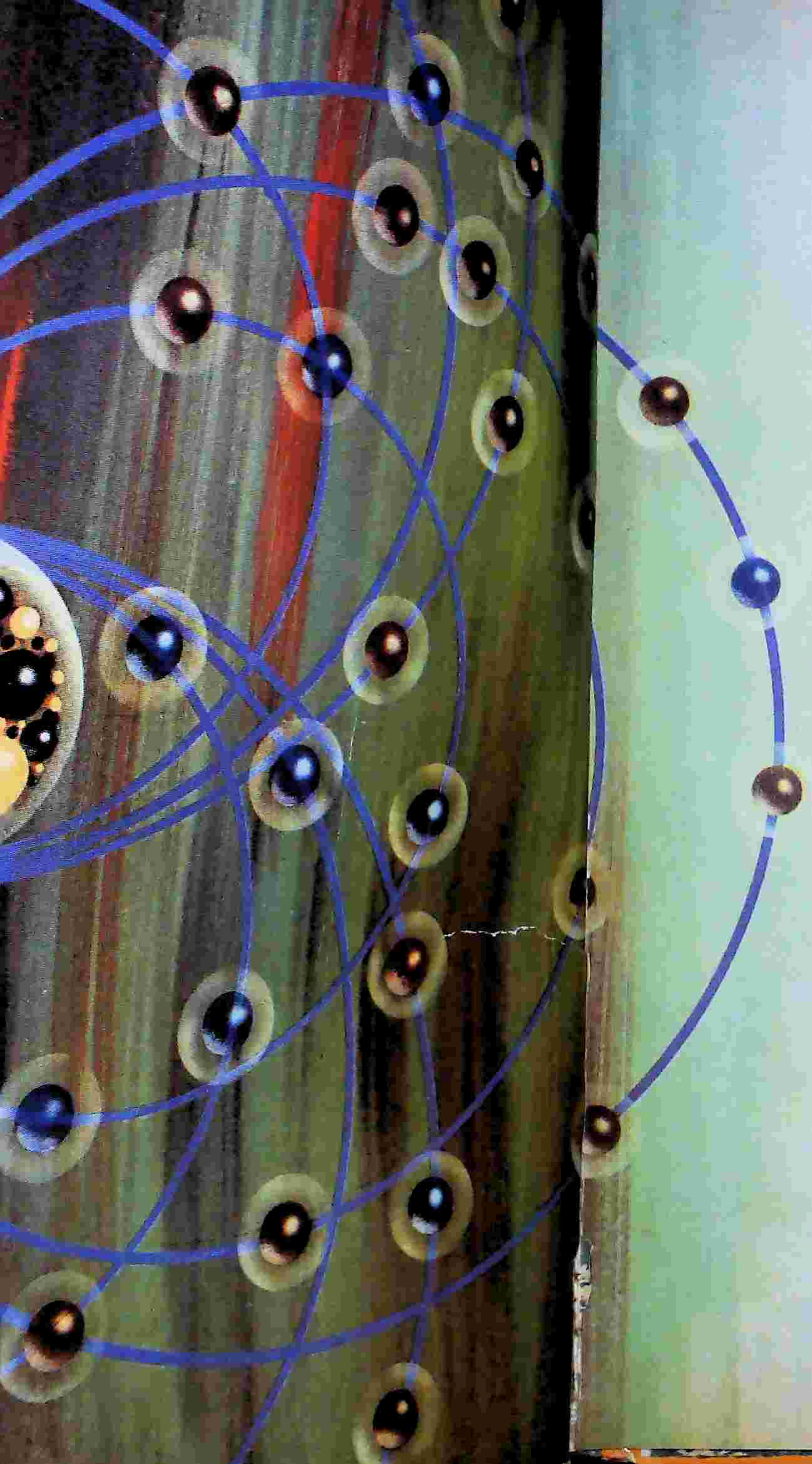

ATOMS

THE CORE OF ALL MATTER

by JERRY KORN

Illustrated by NORBERT VAN HOUTEN

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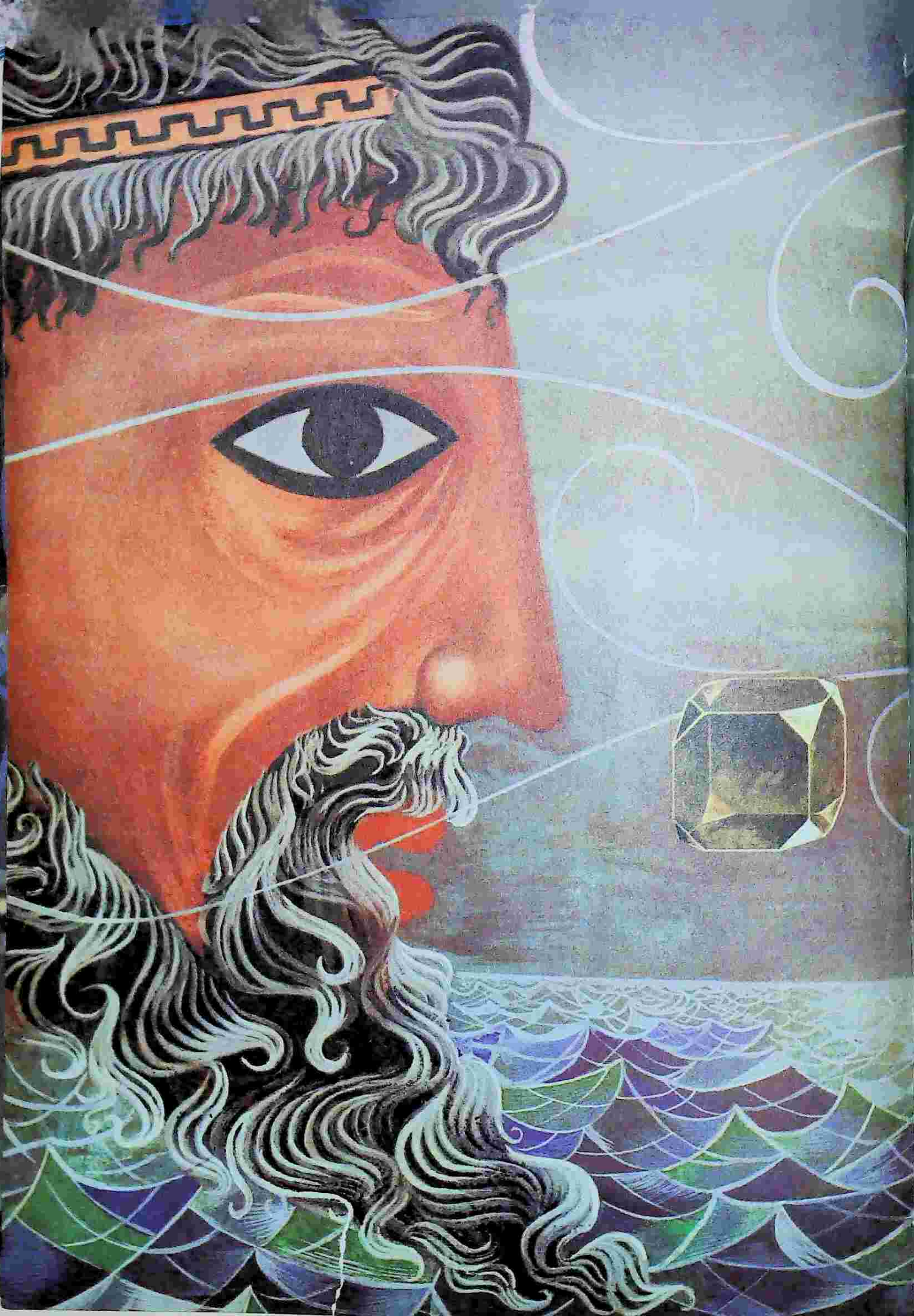
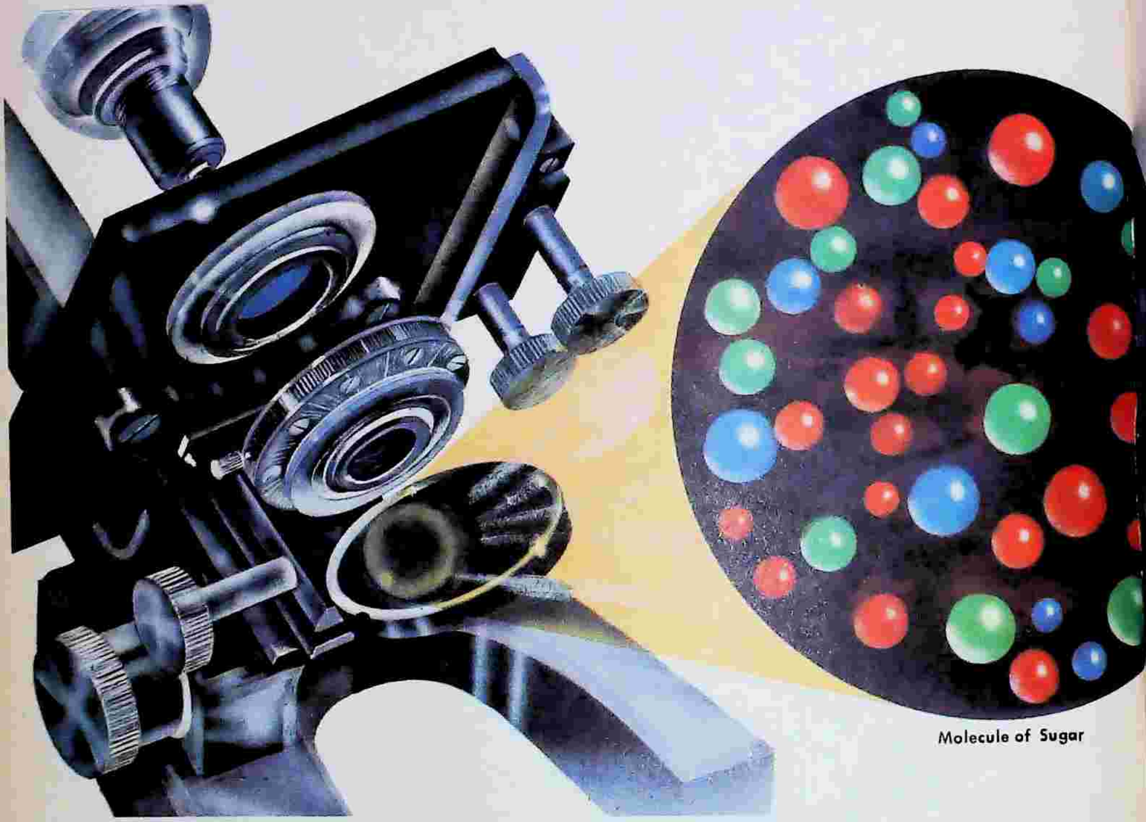


What Is Everything Made Of?

We are now living in the Atomic Age, a period in history that burst upon the world in 1945, with the wartime atomic bomb explosions. These explosions, the most powerful forces ever let loose by man up to that time, were the spectacular answer to a question that has puzzled scientists and philosophers for more than 2,500 years. It is: "What is everything made of?"

The first people who tried to answer this question were the ancient Greeks, who tried hard to find measurable explanations for all the mysteries of the natural world. They came up with some very strange answers. Around 600 B.C. a Greek philosopher named Thales decided that everything must be made of water—one kind of water for the seas, another kind for hard things such as rocks, and so on. Soon afterward, another Greek thinker announced that Thales' theory was obviously nonsense: it was perfectly plain that everything in the world was made of water *and air*.

Another man said that it must be air



Molecule of Sugar

alone and still another said that they were all wrong and that everything was made of fire. And so it went, with one curious theory following another.

Sometime later, a man named Democritus came along with a different notion. Everything that exists, said Democritus—the earth, the sky, the oceans, all vegetation, all creatures—is made up of millions of tiny particles packed closely together, like bees in a swarm. Democritus called these particles atomos, the Greek word for something that cannot be divided or cut apart. This idea of tiny particles seemed so absurd, however, that it was attacked by no less a personage than the famous philosopher Aristotle, one of the greatest Greeks who ever lived. He so thoroughly discredited Democritus' theory that it was more than 2,000 years before scientists gave it serious thought again.

When they did, they realized that there was one thing about the ideas of Democritus that set them apart from all the other strange ideas which had come along earlier. Up to a point, at least, Democritus was right.

If it were possible to look at a crystal of sugar under a giant microscope, you might see one of the crystal's trillions of molecules, each with 45 atoms.

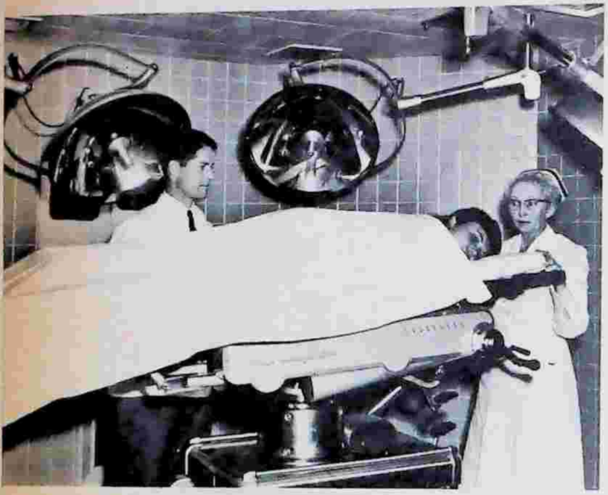
The Wonderful Atom

As we shall see, Democritus had somewhat confused atoms with what we now call molecules, but he was certainly on the right track when he said that they were small. We know now that molecules are tiny objects made up of atoms. Both molecules and atoms are so minute that it is hard just to imagine their size.

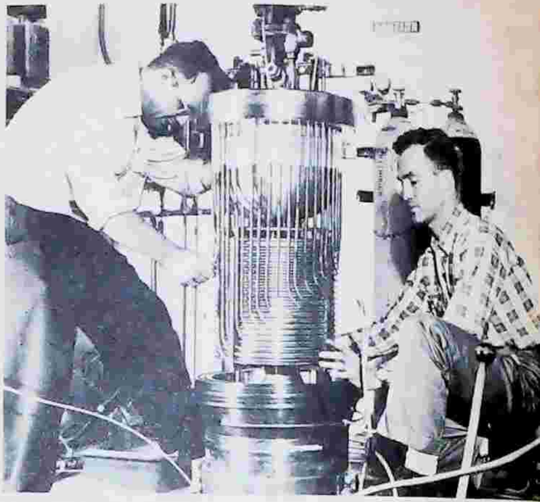
There are only a few different species of atom—about one hundred—but out of them many different kinds of molecules can be made, just as all the words in the English language are built up from only 26 letters.

In order to imagine the size of an atom, look at a grain of sugar. From a few feet away you can't even see it. Yet it contains trillions of molecules, and each one of those molecules contains 45 atoms.

Suppose there were a microscope so powerful that, if you could see your little grain of sugar all at once, it would appear to be as big as the entire earth. You would then be able to see the molecules which make up the grain of sugar, and each of them might appear to be the size of a large house. You would also be able to see the 45 atoms



Atomic energy is used in medicine.



Reactors produce industrial power.

in each molecule, each atom being about the size of a room in the house. But there is something smaller than the atom. It is called the nucleus, and is found in the center of each atom; it would be barely visible as a speck of dust in the middle of the room. And if *that's* hard to believe, think of this: each nucleus is composed of still tinier objects, called protons and neutrons.

You might suppose that when things got that small they just wouldn't matter any more. But they do. For it is when the protons and neutrons inside the nucleus of the atom are blasted apart or fused together, that we get

Atomic energy is already being used to supply power for submarines.

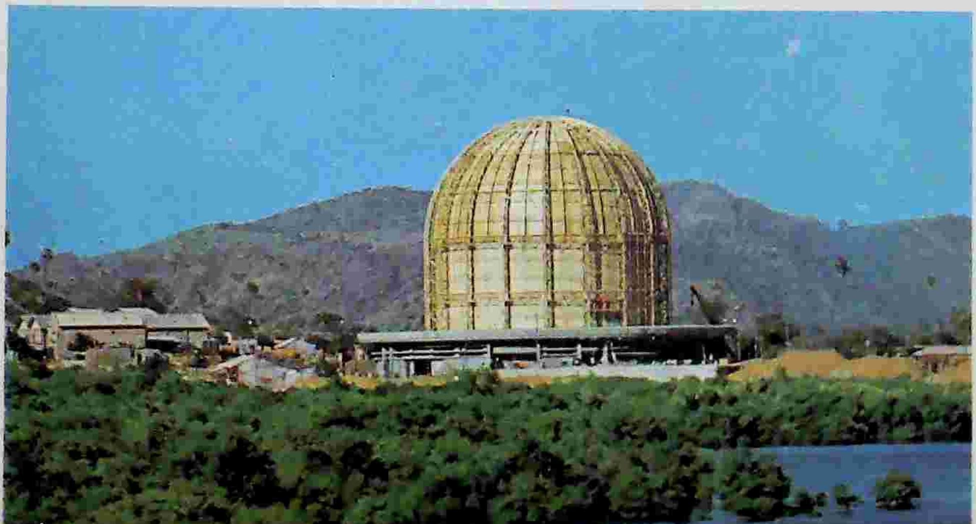
An atomic power plant in India. ►

atomic and hydrogen bombs, atomic power plants in electric stations and in submarines, and all the other wonders of the Atomic Age.

For all of us, the splitting of the nucleus of the atom was one of the most important events of our lives. Atoms are the building blocks of which everything around us is made, and splitting them is rapidly becoming a central part of our day-to-day existence. In future years the splitting and fusing of atoms will run our industries and power our big ships and airplanes. It may help cure many diseases, keep foods fresh for long periods, help to control insect pests, and do so many other things that it would be impossible to list them all.

And perhaps the greatest wonder of all is that these marvels come from the splitting of an object that no one to this day has ever really seen, an object that scientists at first only guessed *must* exist—because without it there was no way to explain how the earth and all the things on it came to be the way they are.

The Thrombay atomic plant will provide India with much-needed power for industry.



The Atom and the Element

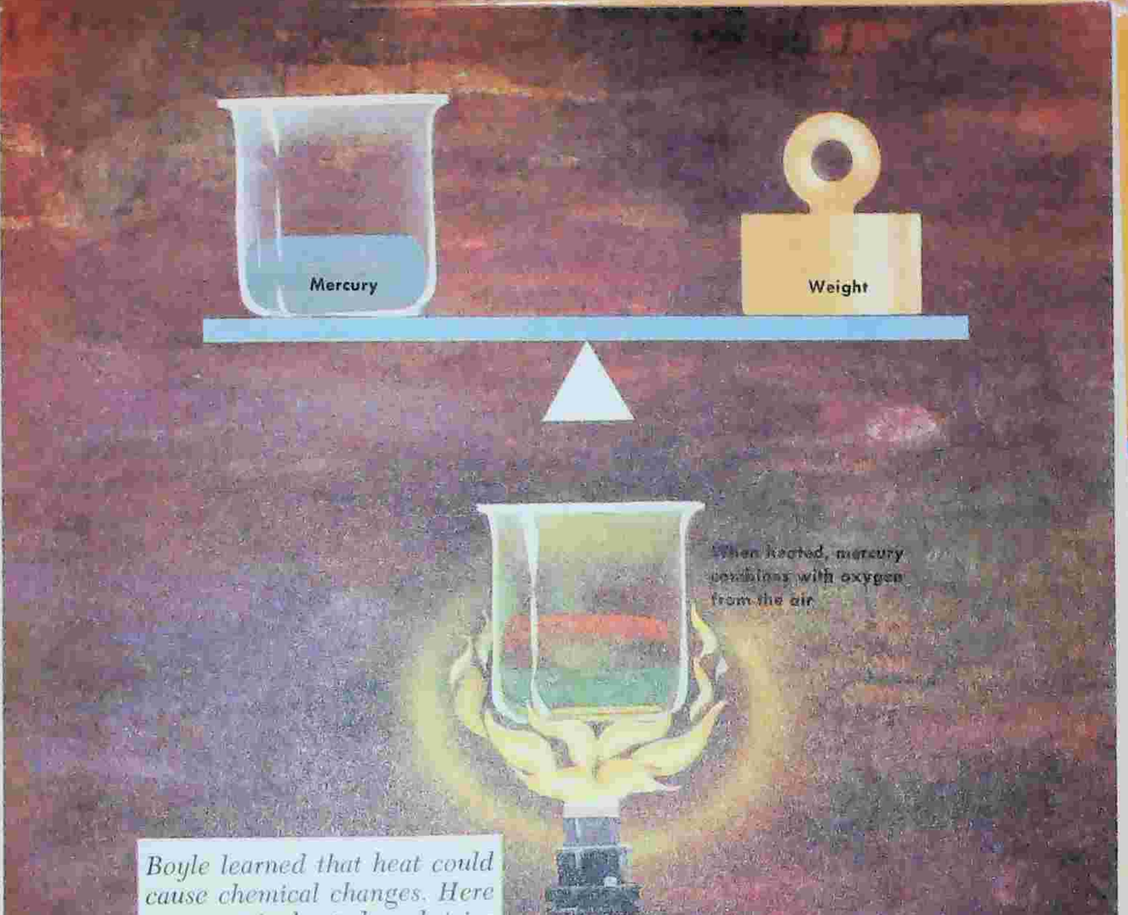
From about 400 B.C. to the late 1500's, the atom was all but forgotten. Aristotle had believed that everything was made of four "elements"—fire, water, earth, and air—a theory which was not much different from the theories of Thales and other early philosophers. Because Aristotle was a wise and learned man, people accepted his idea of the four elements so completely that all real progress in the study of matter simply came to an end for many centuries. (Aristotle's notion of the four elements still lingers on in the saying that a man who goes out into the wind and the rain is "braving the elements.")

During all of this period that was dominated by Aristotle's theory of the four elements there were no scientists as we now know them. Certainly, there were no *chemists* who spent their time investigating the secrets of matter; instead, there were *al*chemists, experimenters who spent their time trying to turn various cheap materials such as lead into gold, so that they or their masters could become rich. Aristotle suggested that this might be possible since all metals were supposedly made of the same four elements.

Finally, nearly 2,000 years after Aristotle, a young Italian mathematician began to question these ancient theories. What was more important, he offered proof through his experiments that many of Aristotle's scientific ideas were wrong. This young Italian's name was Galileo. His contribution to the discovery of the nature of the atom was that he persuaded his fellow scientists, and the world, to accept as fact only those theories which could be proved by actual tests and experiments.

Almost as important was the first scientific use, some years later, of the microscope, by the Dutch scientist, Leeuwenhoek. Now, for the first time, chemists were able to look into a strange, miniature world.

Slowly and laboriously, chemistry began to get back on the right track. In the 1600's a Frenchman named Pierre Gassendi suggested that the atomic theory of Democritus might be right. As time passed, more and more men came to agree. But it was hard to believe in atoms, because anyone who did found himself facing a discouraging set of questions: what were atoms like? how did they look? what made them stick together? were there as many different kinds of atoms as there were many different materials in the world, or were all the things on earth made of the same kind of atom, only somehow arranged differently?


Mercury
Weight
When heated, mercury combines with oxygen from the air
Weight
Mercuric Oxide

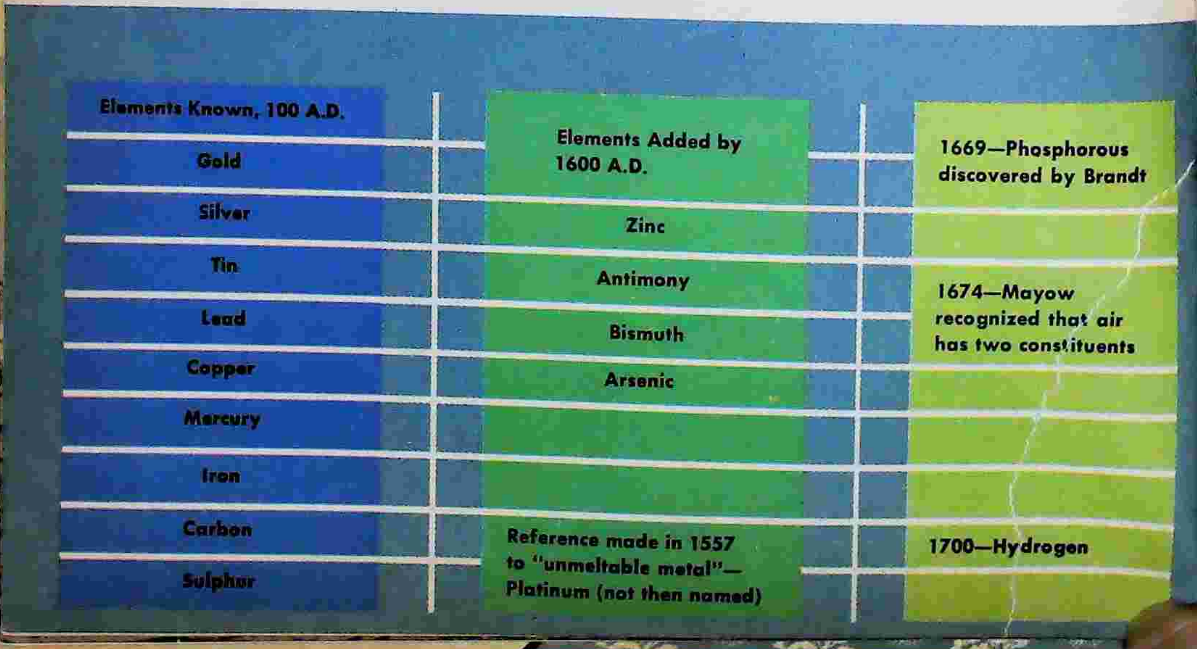
Boyle learned that heat could cause chemical changes. Here mercury is heated and joins with oxygen to form a heavier substance, mercuric oxide

Then, 50 years after Gassendi, an Irish researcher named Robert Boyle came up with a major clue to the mystery of the atom. He did it by combining Aristotle's idea of the existence of elements with the testing methods of the alchemists. The alchemists had tried for many years to make gold by combining other cheaper materials. They had never succeeded. Boyle tried similar experiments, not because he wanted to become rich but because he had a true scientist's curiosity. And gradually he became aware that whereas certain kinds of matter cannot be made by combining others, some can: brass can be made by heating together zinc and copper; salts can be made by combining acids and alkalis. Other materials could be broken down into simpler substances. But gold could not be broken into parts, nor could it be made by combining other materials. The same proved true of copper and of mercury. Why? Well, it must be that these *were* simple substances—the simplest that nature could make. Everything on earth, Boyle concluded in a brilliant flash, must be made of a limited number of simple substances—call them by the old Greek name, elements.

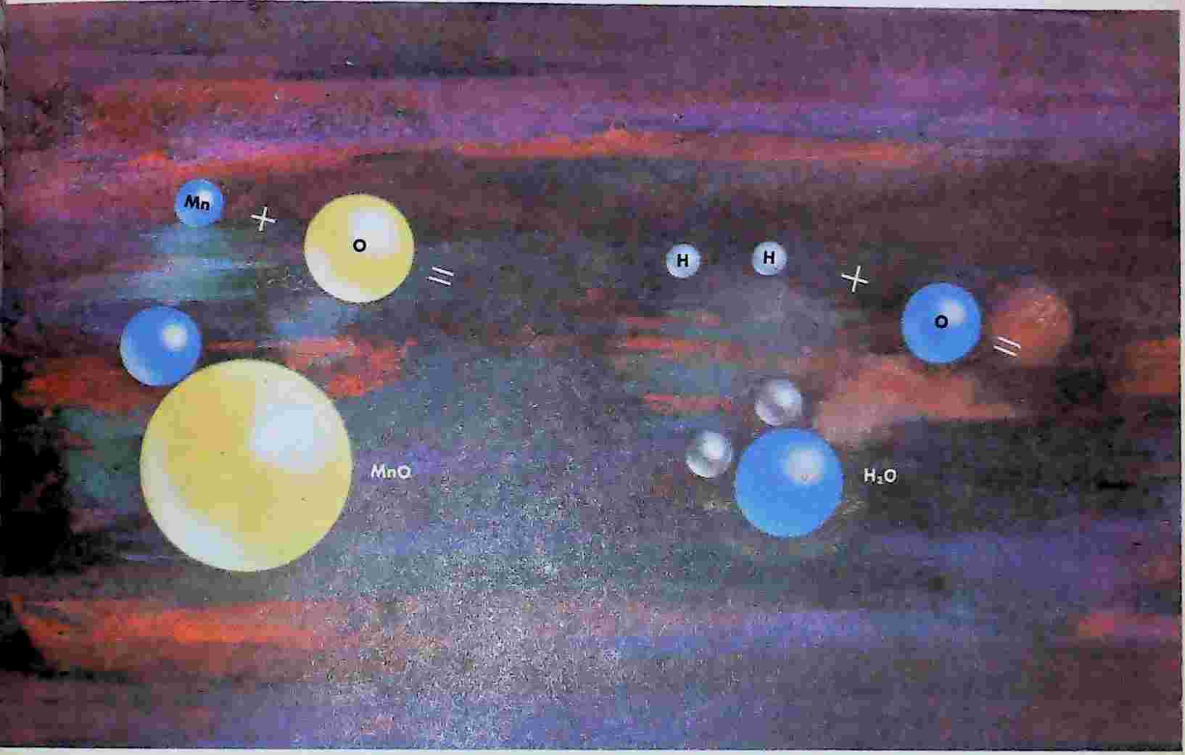
But just what an element is must be determined by chemical experiments, not decided by philosophy as Thales and Aristotle tried to do. Everything on earth that was *not* an element—including such things as air and water—must be made of different elements somehow joined or mixed together.

It was a brilliant theory, and it was correct. Chemical science after Boyle's time was still faced with many unsolved mysteries. But it was now heading in the right direction.

These elements were known in Boyle's time.



Elements Known, 100 A.D.	**Elements Added by 1600 A.D.**	
Gold		**1669—Phosphorous discovered by Brandt**
Silver	**Zinc**	
Tin	**Antimony**	**1674—Mayow recognized that air has two constituents**
Lead	**Bismuth**	
Copper	**Arsenic**	
Mercury		
Iron		
Carbon	**Reference made in 1557 to "unmeltable metal"—Platinum (not then named)**	**1700—Hydrogen**
Sulphur		

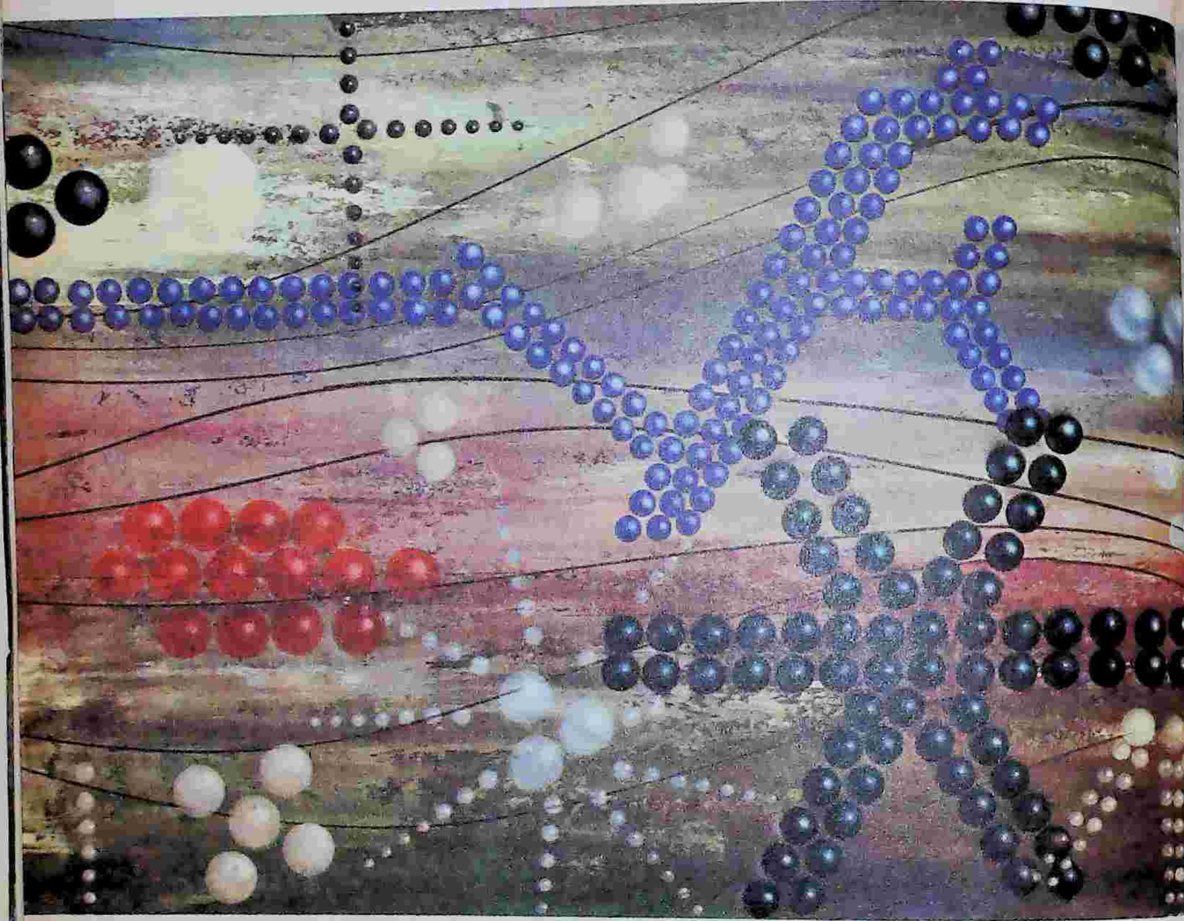


Many elements made new substances when joined together: manganese and oxygen made manganese oxide (MnO), hydrogen and oxygen made water (H_2O).

Dalton Finds the Key

Now that Boyle had shown the way, there was a ferment of scientific activity all over Europe. More elements turned up. Two British scientists, Cavendish and Priestley, discovered hydrogen and oxygen. A Frenchman, Lavoisier, found nitrogen; a German, Scheele, found chlorine. Unlike gold, silver, sulfur, phosphorus, and other elements identified by Boyle, all of which were solids, these were gases—some colorless and invisible; others, like chlorine, colored and strong-smelling.

It was also discovered now that two of these gases, hydrogen and oxygen, when joined together made up water, which was a liquid. Furthermore, and most fascinating of all, they always joined together in exactly the



Atoms of one element are alike, but are never like atoms of other elements.

same proportions. The recipe never changed. To convert one pound of hydrogen into water, you had to use eight pounds of oxygen every time. So pure water always had the same composition—eight parts, by weight, of oxygen, one of hydrogen. And the same pattern was observed when other elements formed combinations—or compounds, as they came to be called. When sodium and chlorine were combined to make salt, or carbon and oxygen formed carbon dioxide—for any given compound the recipe—the exact proportions of the elements in it—were always the same.

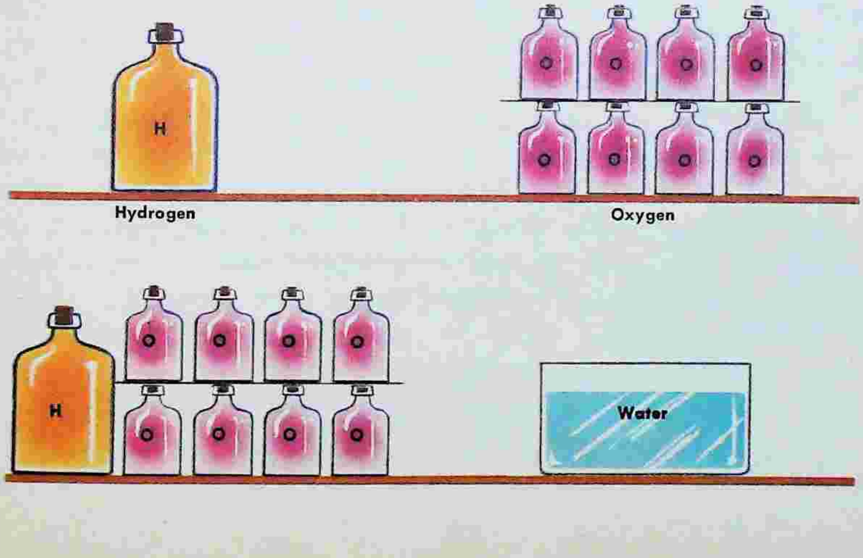
But why? What magical thing happened when oxygen met hydrogen? Chemists could mix other elements together—say, hydrogen and copper—and get absolutely nothing. The discoveries had been coming thick and fast, but they made no sense. Somewhere there had to be a key, an explanation that would make all these bits and pieces fit together.

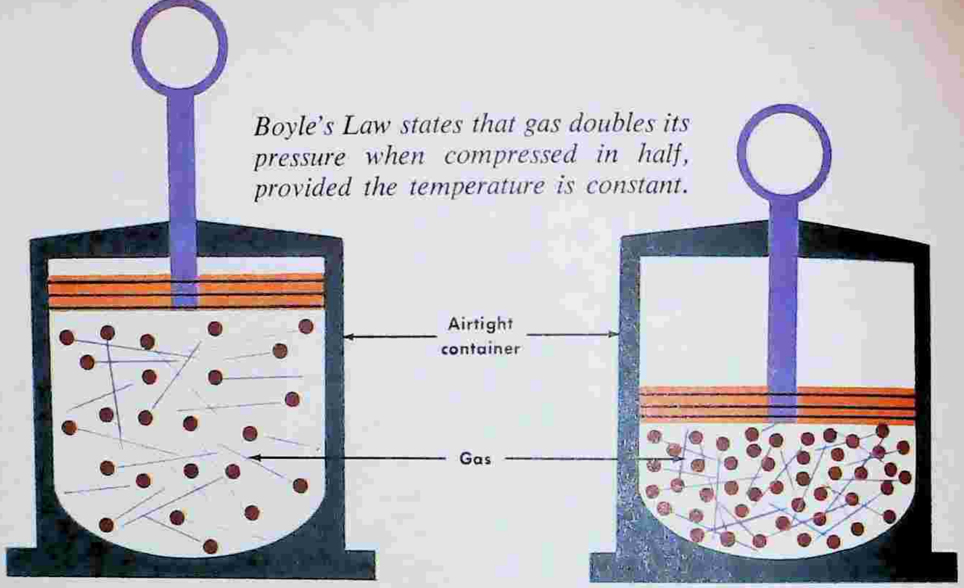
A British schoolmaster found it. The explanation was Democritus' old idea, the atom.

John Dalton knew that when various elements were seen through a microscope they appeared in the shapes of different kinds of crystals. Crystals of gold always looked alike, crystals of copper always looked alike, but crystals of gold and copper never looked like each other. Therefore, he concluded, atoms of these substances must have the same characteristics: all atoms of gold had a family resemblance as did copper atoms, but the two kinds of atoms were not like each other.

Compounds, like water, must consist of regular groupings of atoms, but of different kinds. Water would be a combination of oxygen and hydrogen atoms. And, said Dalton, the reason eight ounces of oxygen always combines with one ounce of hydrogen must be that eight ounces of oxygen must have the same number of atoms as one of hydrogen—and they combine atom for atom. Therefore, Dalton concluded, water consists of uncountable numbers of double-atoms—one atom of hydrogen combined with one atom of oxygen—with each oxygen atom being eight times as heavy as each hydrogen atom. It was a simple and wonderful idea. Without this push in the right direction science might still be floundering in confusion. For thinking of it Dalton is called the originator of modern atomic theory.

Dalton thought each oxygen atom was eight times as heavy as a hydrogen atom. Therefore, eight parts by weight, of oxygen join one part by weight, of hydrogen to make water.





Boyle's Law states that gas doubles its pressure when compressed in half, provided the temperature is constant.

Avogadro's "Little Masses"

There was a possible error in Dalton's theory. He had figured that oxygen atoms weighed eight times as much as hydrogen atoms, and that in water the numbers of the two kinds of atoms were equal. But suppose oxygen weighed, say, 32 times as much as hydrogen. Then there would have to be *four* atoms of hydrogen for every one of oxygen to explain the eight-to-one proportion. This was not impossible: the one-to-one proportion was in particular made uncertain by the fact that sometimes two elements formed several different compounds. The one-to-one rule obviously couldn't be correct for all of them!

Nobody knew the true comparative weights of the atoms of the various elements, so nobody could tell how atoms joined together in compounds.

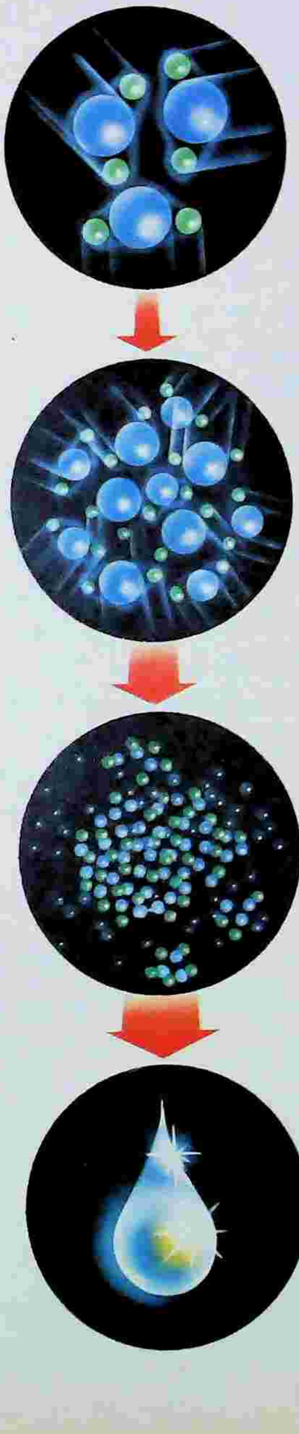
This problem was finally solved in 1811 by a great Italian physicist, Amadeo Avogadro. Many years before, Robert Boyle had made an interesting discovery. Suppose a gas, such as hydrogen or oxygen, is placed in a bottle. The gas will press lightly against the bottle's sides. Now suppose that the same amount of gas, held at the same temperature, is squeezed into a bottle half the size of the first one. It is now found that the gas pushes twice as hard against the sides of the bottle.

This became known as Boyle's Law. In simple language it states that any amount of gas enclosed in a container will double its pressure if it is squeezed into half the space, triple its pressure in one-third the space, and so on, provided the temperature remains the same in each instance.

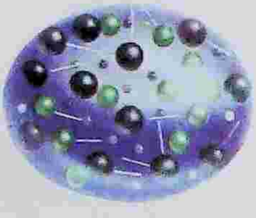
Using Boyle's Law as the basis for further studies, Avogadro suddenly made an inspired guess: If *two* gases are placed in bottles the same size and if, at the same temperature, they exert the same pressure, then there must be the same number of gas particles in each bottle. Now all he had to do to find how much an oxygen atom weighed, compared to a hydrogen atom, was to measure off equal amounts of oxygen and hydrogen by his new method and see how much each weighed.

Oxygen weighed 16 times as much as hydrogen. In order to make water (with eight times as much oxygen, by weight, as hydrogen), *two* hydrogen atoms had to join *one* oxygen atom. Chemists abbreviate the names of the elements, calling them by their initials; oxygen and hydrogen become O and H. Dalton had suggested that water was made of HO, meaning one atom of H and one of O. Now Avogadro had discovered that the correct formula was H_2O. The hookup of atoms was more complicated than Dalton had thought, and it was later discovered that in certain other compounds it was even more complex. A molecule of sugar, for example, is composed of 45 atoms—12 of carbon (C), 22 of hydrogen (H), and 11 of oxygen (O). Written in a scientific way, it is $C_{12}H_{22}O_{11}$. Such clusters of atoms needed a name, and Avogadro coined one: "Molecules," or "little masses."

Now at last men were beginning to discover the answers to the question, what is everything made of? All matter is made up of elements and compounds. The elements are made of molecules and identical atoms. The compounds are made of different kinds of atoms, joined together in molecules.



Tiny electrical forces between the molecules of water vapor cause thousands of them to join together to form visible water droplets.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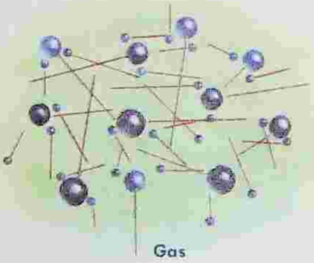
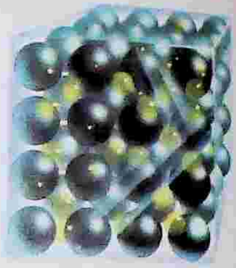

Gas


Solid

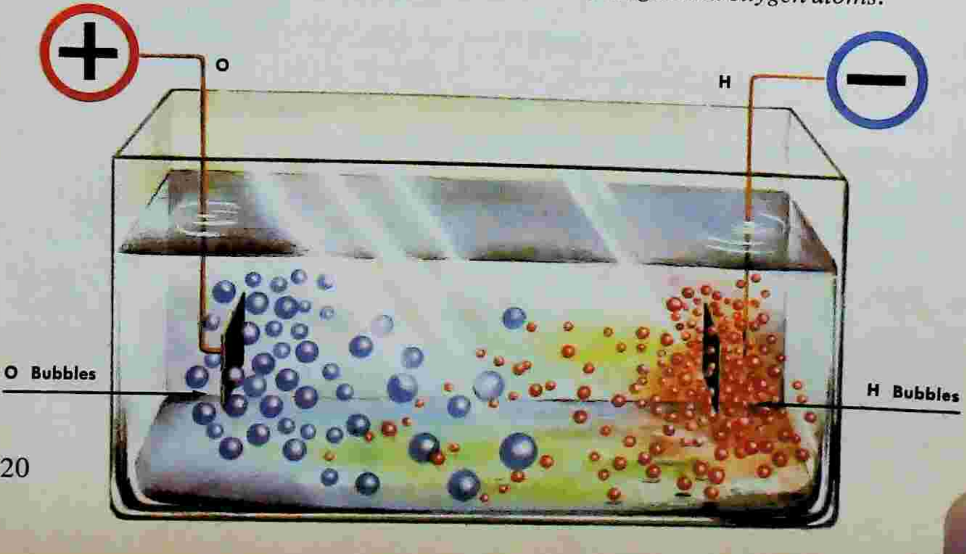
The Electric Particles

In the 50 years following Avogadro's experiments, a great deal was learned about chemistry and physics. It was discovered that both atoms and molecules move—fairly long distances in liquids and gases, barely quivering in solids. Many new elements were discovered. Each, of course, had its own atom, and each had a weight different from the others.

Yet very little was done during that time to dig deeper into the basic structure and inner working of the atom. Then, suddenly, investigation of the atom began to move swiftly. By 1900, scientists had learned about the force that makes atoms cling together in molecules. They were pushing into new and exciting fields so fast that experimenters in many parts of the world could barely manage to keep up with one another.

At the heart of this sudden advance lay a force which had been known

Electricity can turn water molecules back into hydrogen and oxygen atoms.



even longer than the atom itself—electricity. In fact, it was Thales of Greece who had given electricity its name. Thales had found that when he rubbed the yellow fossil material, amber, a force was created which would attract bits of cloth and other substances to the amber. Thales named this strange force electricity, after the Greek word for friction, *elektron*.

Later scientists found that many other objects would produce the same attraction when rubbed together. They also learned that whatever caused this attraction—whatever electricity was—could be made to travel along a wire. And they discovered one other strange thing: at times, instead of being attracted to each other, substances which contained electricity would repel each other—actually be pushed apart. Benjamin Franklin, who was not only a great leader of the American Revolution but was also the first great American scientist, concluded that there must be two kinds of electricity. He called one "negative" and the other "positive." Substances with charges of negative electricity repelled each other, as did two substances with positive charges. But a negative charge and a positive charge attracted each other.

Franklin also tried to figure out what caused electrical forces. Perhaps, he said, electricity is a kind of matter, and perhaps electrical matter consists of particles.

Almost 100 years after Franklin's death, the first proof came in the form of a startling discovery. If negative and positive terminals were placed in a solution of salty water, bubbles of hydrogen would arise from the negative terminal and bubbles of oxygen from the positive terminal, and after awhile, the water would disappear. The elec-

Electricity passing through a vacuum tube produced a strange glow at one end.

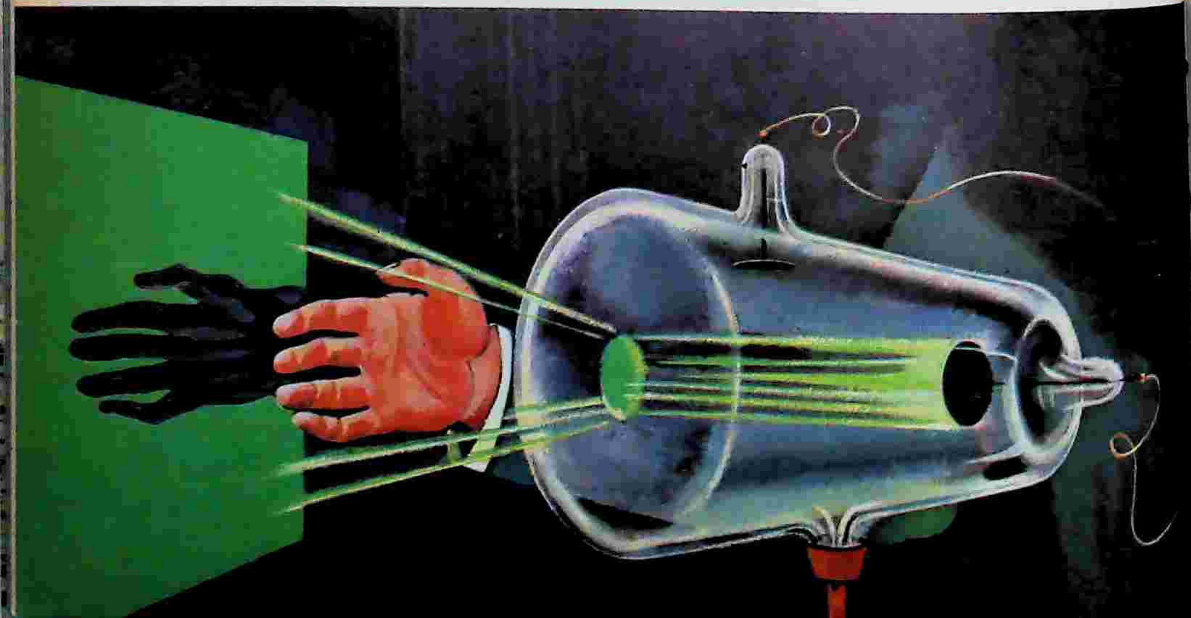
tricity was breaking up the molecules of water, ripping their atoms apart, turning the water into its separate elements, hydrogen and oxygen!

Somehow the electric current was canceling out whatever it was that held the molecules together. Ever since Dalton's discoveries scientists had been wondering what force kept different kinds of atoms joined together in molecules. Now it seemed that this force must be electricity. For the first time, researchers began to think of the atom as containing electrical charges. Atoms themselves are usually neutral—they have neither a positive nor a negative charge. But deep within them there must be both kinds of electricity—in equal amounts, of course.

In the later years of the 19th century, scientists began to experiment with electrical currents passing through a tube of glass from which almost all the air had been pumped out. They got some curious results. For one thing, a strange glow appeared at one end of the tube. Rays of some kind must be emerging from the wire-end (called the electrode) at one side of the tube, and lighting up the glass on the other side. Furthermore, it soon became clear that these were not ordinary light rays. A magnet placed beside the tube would make them swerve from their course—and magnets have no effect on light. These must be charged particles —the very particles of electricity that Franklin had forecast more than 100 years before. The scientists named them "electrons."

Later, it was found that some tubes produced other rays which could *not* be bent by a magnet. One day in 1895 a German scientist named Wilhelm

The bones of Roentgen's hand became visible under the strange X-rays.



Uranium gave off rays which, like X-rays, would blacken photographic paper.

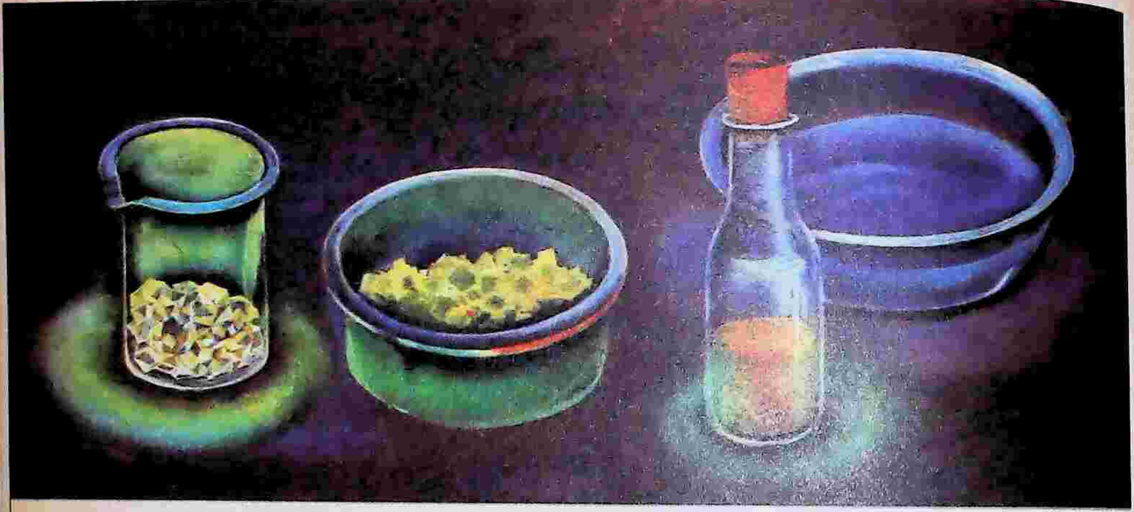
Roentgen was experimenting with the electron rays, when he noticed that a coated paper screen placed near the tube, lit up with a fluorescent glow. Roentgen happened to pass his hand between the rays and the screen. To his amazement, the shadow of his hand did not appear on the screen, as you might expect, but the shadow of the bones inside his hand appeared instead! Invisible rays were passing right through the flesh of his hand and lighting the screen, but enough of them were stopped by the bones to produce a clear shadow of the hand's skeleton. Roentgen had discovered the X-ray.

Roentgen's discovery, of course, revolutionized the diagnosis of human ailments. The medical world quickly appreciated the great advantage of being able to observe the position of bones and the body's organs without having to resort to surgery.

Besides leaving a picture on a screen, Roentgen's rays would print a picture on photographic paper. Not long after the discovery of the X-ray, a French scientist named Henri Becquerel made another important discovery. Becquerel had become interested in a relatively little-known element called uranium, because it had certain unusual properties which made him think it might have some connection with Roentgen's X-rays.

At that time, it was known that when uranium was added to other materials to form uranium salts, the salts gave off a faint glow, or fluorescence, for a short while after being exposed to sunlight. Becquerel also found that uranium, as well as all its compounds, gave off rays which, like X-rays, would also blacken photographic paper—right through the paper's outer wrappings. Here was a curious thing: an element that gave off rays without any apparent reason.

Becquerel had discovered radioactivity although it would be some years before this process was fully understood. In Becquerel's time, however, the discovery was another important milestone in the march toward the atomic era.



The Curies kept refining samples of uranium ore until only a bit was left.

An Exciting New Element

Henri Becquerel made one other discovery almost as important as his finding of the rays given off by uranium. When he tested some of the ore in which uranium is found, he noted that it was giving off even more and stronger rays than those of pure uranium! No element then known gave off such rays. It could, therefore, only be an unknown element contained in uranium ore—and one with fascinating possibilities. There was just one trouble: no ordinary chemical test revealed the presence of this mystery element.

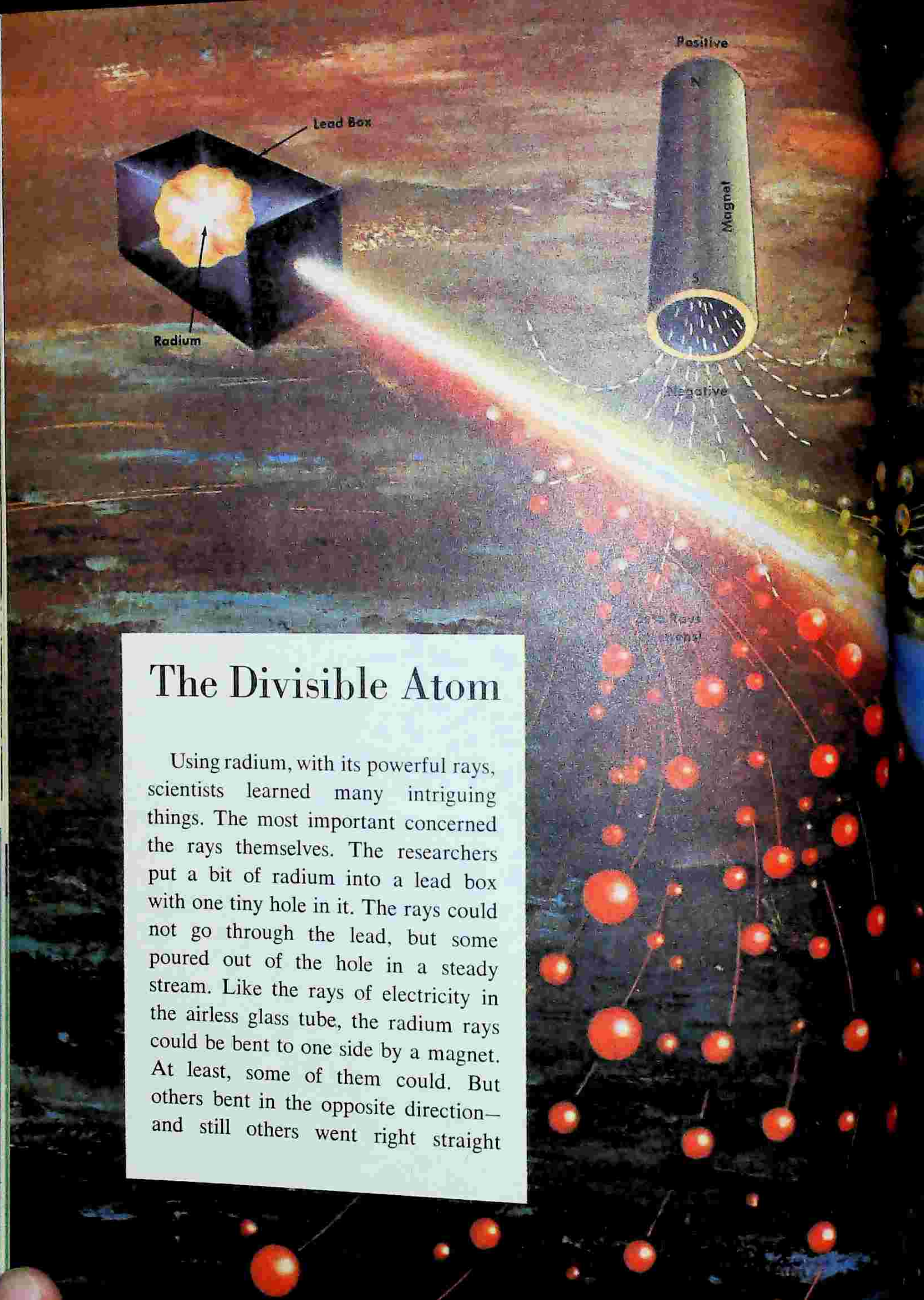
The search, one of the most dramatic in the history of science, was taken up by a young husband-and-wife team of researchers. The French physicist, Pierre Curie, and his Polish-born chemist wife, Marie, got a ton of Becquerel's ore and began to test it. They checked and discarded sample after sample, combing out impurities, trying to eliminate everything but the part of the ore that was emitting the rays. Patiently and laboriously, they worked until they had thrown away most of the ton. After a time they had nothing left but a very small amount of the element called bismuth, with certain impurities left in it. Bismuth was well known—it was the impurities that interested the Curies.

One of the impurities turned out to be a new radioactive element which, just as Becquerel had predicted, gave off more plentiful rays than uranium did. Marie Curie named the new element polonium, in honor of her native land. It was a wonderful discovery, but it only increased their curiosity, for something in the original ore was giving off even more radiations than the polonium did!

At last, nearly four years after the search had begun, the two scientists found the mystery substance—an element so powerful that when their friend Becquerel later tried to carry some in his pocket, he suffered a bad burn. Because of its rays, the Curies named the new element radium. Their long search through a ton of ore had produced just a few crystals of the stuff—about as much as you might get from one jiggle of a salt shaker.

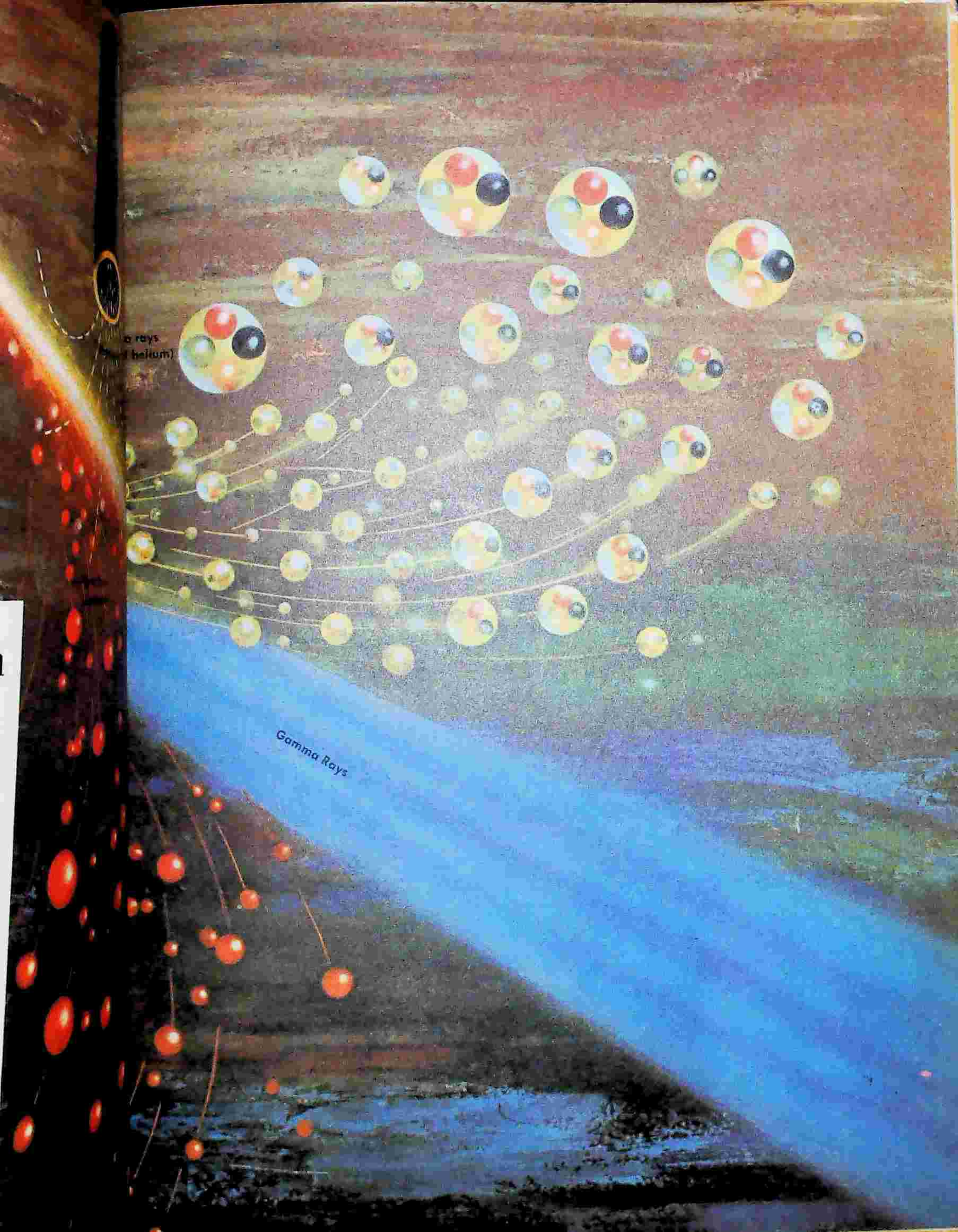
In the years to come, many uses would be found for radium. But the most important thing about it was that it remained warmer than its surroundings. It was not only giving off rays, but also heat. Some day a great genius would explain the source of this mysterious warmth, and his explanation would lead to great discoveries.

Magnified many thousands of times, a crystal of radium would look like this.



The Divisible Atom

Using radium, with its powerful rays, scientists learned many intriguing things. The most important concerned the rays themselves. The researchers put a bit of radium into a lead box with one tiny hole in it. The rays could not go through the lead, but some poured out of the hole in a steady stream. Like the rays of electricity in the airless glass tube, the radium rays could be bent to one side by a magnet. At least, some of them could. But others bent in the opposite direction—and still others went right straight


a rays
helium)
Gamma Rays

ahead as if there had been no magnet there at all!

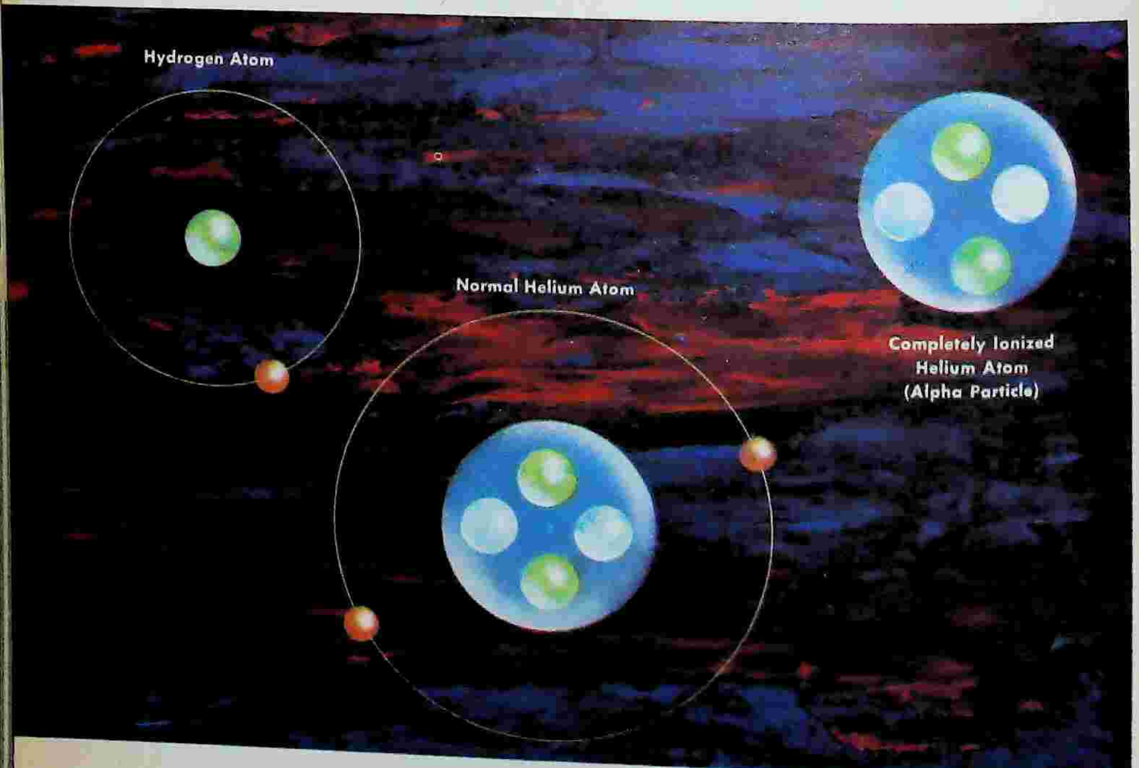
The two kinds of rays that bent were named alpha and beta rays after the first two letters of the Greek alphabet. The rays that went straight ahead were named gamma rays after the third letter. Further investigation showed that the negative rays, the betas, were electrons, but moving much faster than any known before; and the gamma rays were like Roentgen's X-rays, which also whizzed right past the magnet as if it weren't even there.

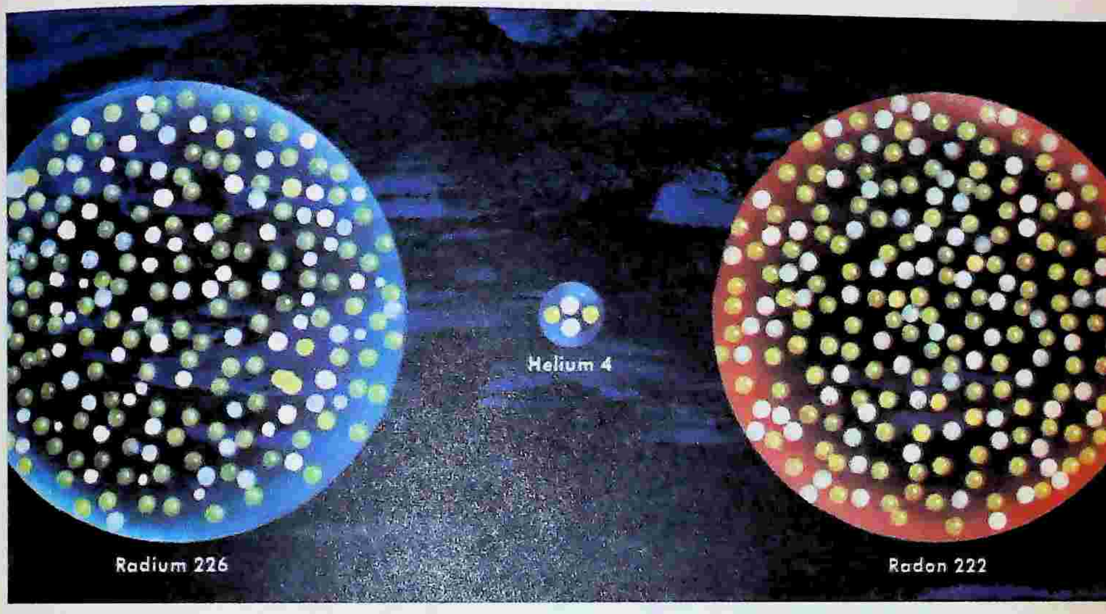
But the alpha rays were something new—and puzzling. They were comparatively slow-moving and they didn't penetrate as deeply as, for example, the gamma rays did. Nobody had seen anything like them.

Finally, a team of scientists, Sir Ernest Rutherford of New Zealand and an Englishman, Frederick Soddy, figured out where *all* the rays came from—and in doing so they finally identified the alpha ray.

Radioactivity—the process of giving off rays—was nothing more or less than

An ionized helium atom (right) has no electrons spinning about its nucleus as normal helium (center) has. At left, for comparison, is an atom of hydrogen.





Radium breaks up into helium and radon, which total the same atomic weight.

atoms breaking up, said the two physicists. These particular atoms were somehow out of balance, or in the scientific term, unstable—a little like a house of cards with too many cards on one side. Like houses of cards, the radioactive atoms kept flying apart, and the three kinds of particles were created when the atoms broke up.

As for the nature of the alpha particle, the explanation was simple but sensational. This particle had been found to weigh four times as much as hydrogen, the same weight as the atom of helium. And ionized helium – an atom that has been turned into an electrified particle – is just what the alpha particle turned out to be! The radium atom was producing the atom of an entirely different element every time it shot out an alpha particle. What's more, still another element—one never before detected – was left behind. When an atom of radium broke up, it turned into one atom of helium and one atom of the new element, which was now named "radon." Radium's atomic weight was 226, helium's was 4, and radon's was 222.

And that was when scientists realized that they had been calling the atom by the wrong name for years. It was not, as Democritus had thought, a tiny object that could not be divided into smaller parts. Not only was it possible to divide radium atoms—it was impossible to stop them from dividing by themselves!

Energy from the Atom

At this point a brilliant physicist named Albert Einstein entered the picture with a theory that revolutionized science. The thing that makes machines run, trees grow, men walk, and bombs explode is known to scientists as energy. Einstein's theory was simple: Everything on earth contains energy; and all matter and all energy are equivalent–that is, matter is energy in a stable state.

Furthermore, Einstein figured a way to calculate this energy. To determine how much there might be in an atom, he multiplied the speed of light by itself, that is, he squared it, then multiplied that figure by the mass of the atom. When he expressed this idea in a formula it came out as a brief $E = mc^2$. E in this formula stands for "energy," m means "mass," c means the speed of light. If m is measured in grams (1/25 ounce), then the squared speed of light, measured in centimeters, equals 9,000,000,000,000,000,000. According to this formula, one ounce of matter changed into energy would keep a 100-watt bulb lit for a million years!

In other words, Einstein was talking about atomic energy for the first time.

It was apparent that one kind of atom, at least, was already giving off a little of its energy. The bit of warmth that had been detected in radium meant that active matter was bouncing around inside the mass; and the little bit that had escaped in the form of radiation was producing heat, which is a form of energy.

It was in 1905 that Einstein unlocked the door that later led to the control and harnessing of atomic energy. It had taken 2,500 years for Democritus' idea to evolve this point, and almost 100 years had passed since Dalton first began to explore it scien-

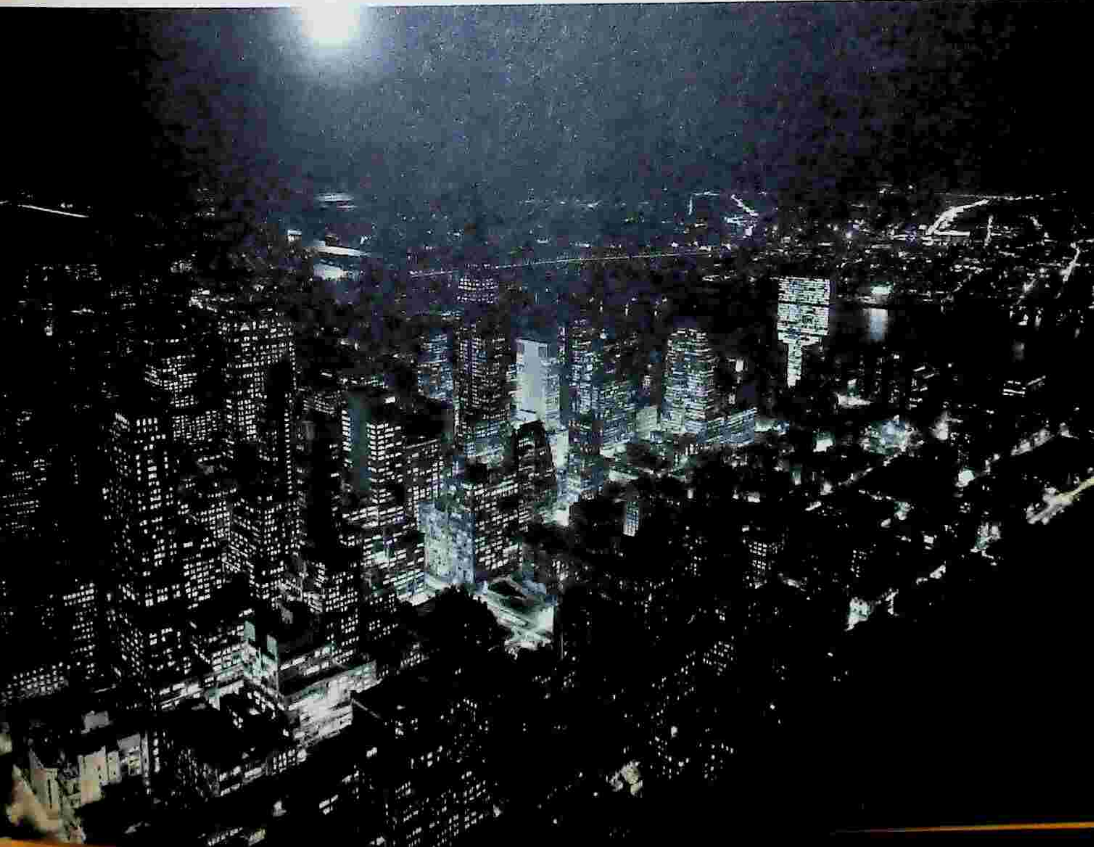
Einstein was the first scientist to see that matter was "frozen" energy.

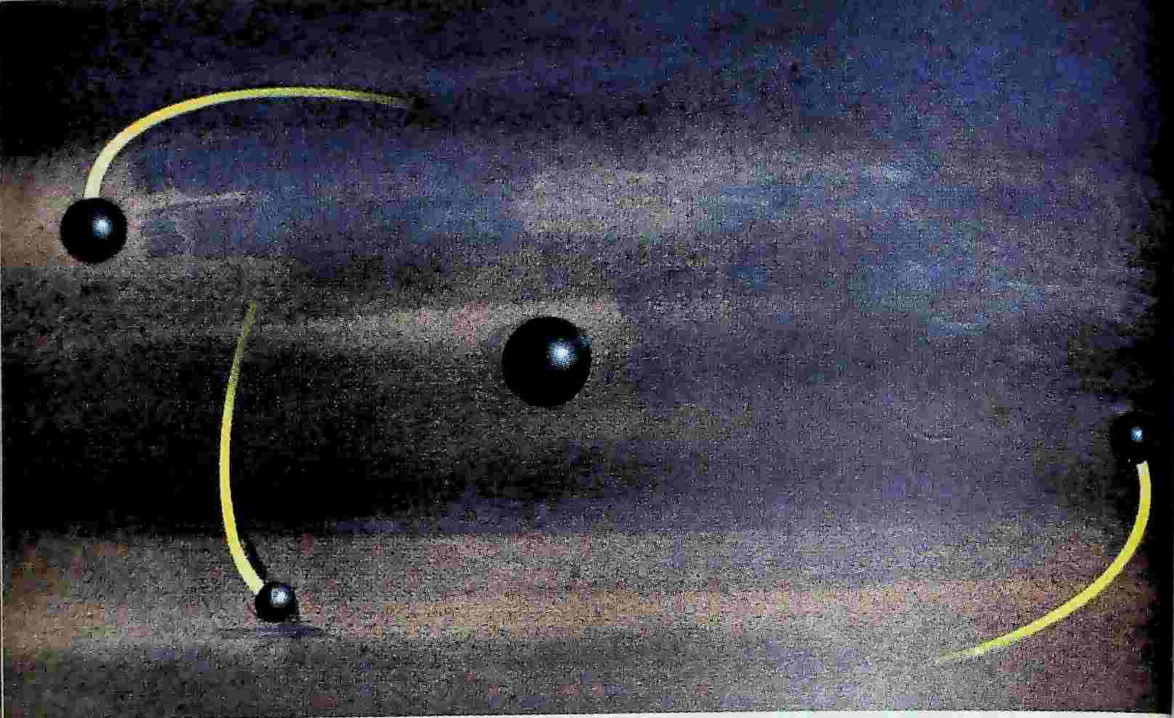
tifically. But now, in the 40 years after Einstein, atomic science was to push on with bewildering speed.

As the researchers headed into the most dramatic period of atomic science, what did they actually know about the atom? Here again, briefly, are the facts they had to work with.

Scientists had discovered that every solid, liquid, or gas—in other words everything—was either an element, the simplest substance, or a compound made up of two or more elements. (Or, of course, a mixture in which two or more elements were brought together but remained separate, like sand and water.) The building blocks of the elements were simple atoms. The building blocks of the compounds were molecules, composed of two or more atoms hooked together by some sort of electrical attraction. Certain elements were radioactive—that is, their atoms were somehow out of balance so that they kept creating positively charged alpha particles (or helium atoms), negatively charged beta particles (electrons), and gamma rays (similar to X-rays) that had no electrical charge at all. This process released energy. If it were possible to make the atom release energy when desired, the resulting force would be greater than any ever before known.

If one gram of matter were converted into energy, it would supply about 1,000,000 kilowatts for a whole day or keep a 100-watt bulb lit for 40,000 years.





An atom is composed mainly of empty space.

The Empty Atom

In 1911, Sir Ernest Rutherford, the New Zealand scientist who had helped explain radioactivity, tried an ingenious experiment.

Rutherford placed some radium in a lead box with a hole in it, and arranged things so that a steady stream of alpha particles poured from the hole. In the path of this stream he placed a glass screen, like Roentgen's, treated with fluorescent chemicals so that it would light up as each particle struck it. Between the lead box and the screen, right in the path of the particles, he placed an extremely thin sheet of gold foil. As thin as the gold was, it was hundreds of atoms thick—in theory, thick enough to stop the alpha particles the way a wall stops a stream of water. But it didn't. The alpha particles passed through the sheet of foil as if the gold atoms consisted of nothing but empty space!

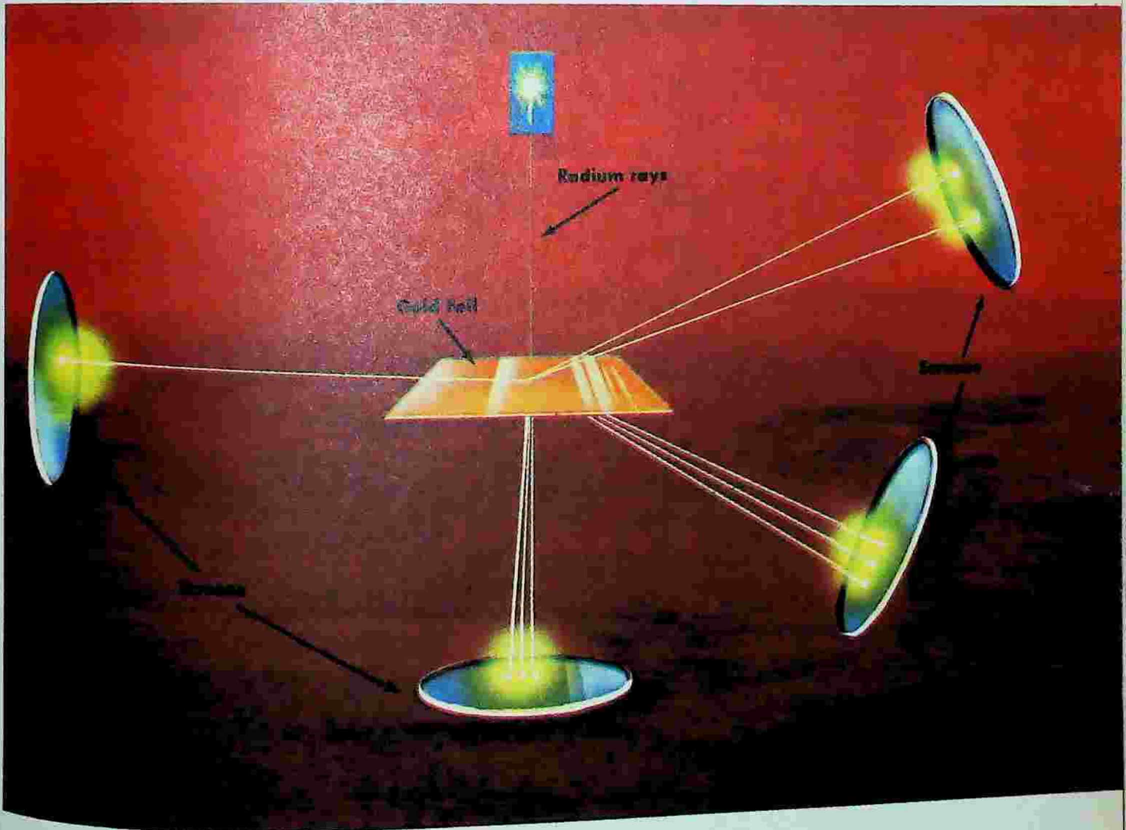
But wait—not all the particles *did* go through. Rutherford placed another fluorescent screen at the side. It showed tiny flecks of light, indicating that a few of the particles were bouncing off the gold atoms at an angle, and making "sparks" on the side screen. A few particles were even bouncing right back toward the lead box!

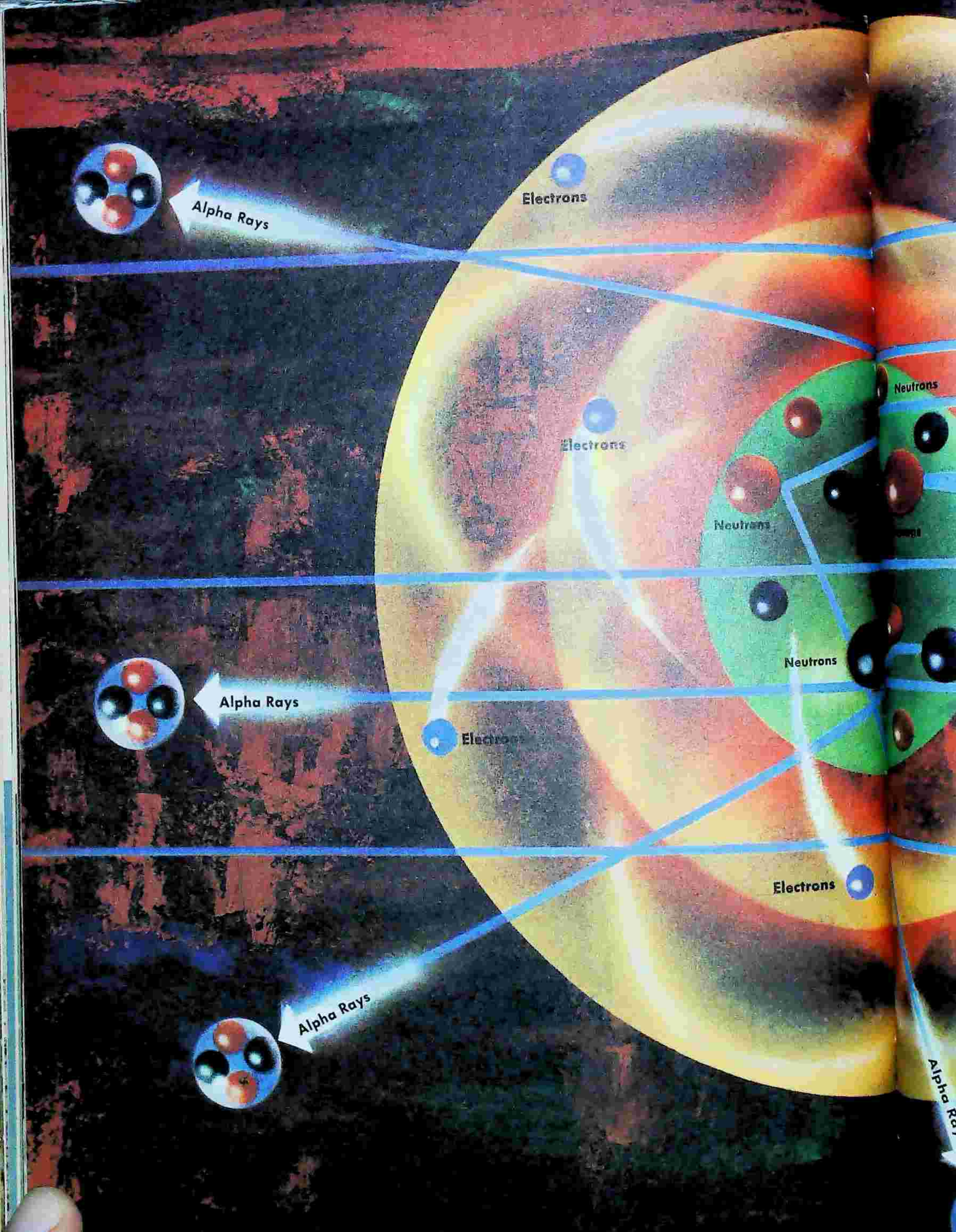
Rutherford counted the number of particles that got through and the number that bounced off, and then announced the greatest discovery yet made about the construction of the atom itself.

The reason most of the particles shot right through the gold atoms, Rutherford said, is that atoms are mostly space. But each contains within it a tiny, positively charged core. When the alpha particles, also positively charged, came near this core they were repelled, because positive charges repel each other. Sometimes the particles were merely turned off their straight path, sometimes they were violently hurled back in the direction from which they had come. Judging from the number of hits and misses, the core might be as much as 50,000 times smaller than the rest of the atom surrounding it.

Rutherford called this core the atom's nucleus. Science now had a new object to study—and an important one.

Rutherford shot alpha rays into gold foil and found that they flew off in all directions.




Electrons
Alpha Rays
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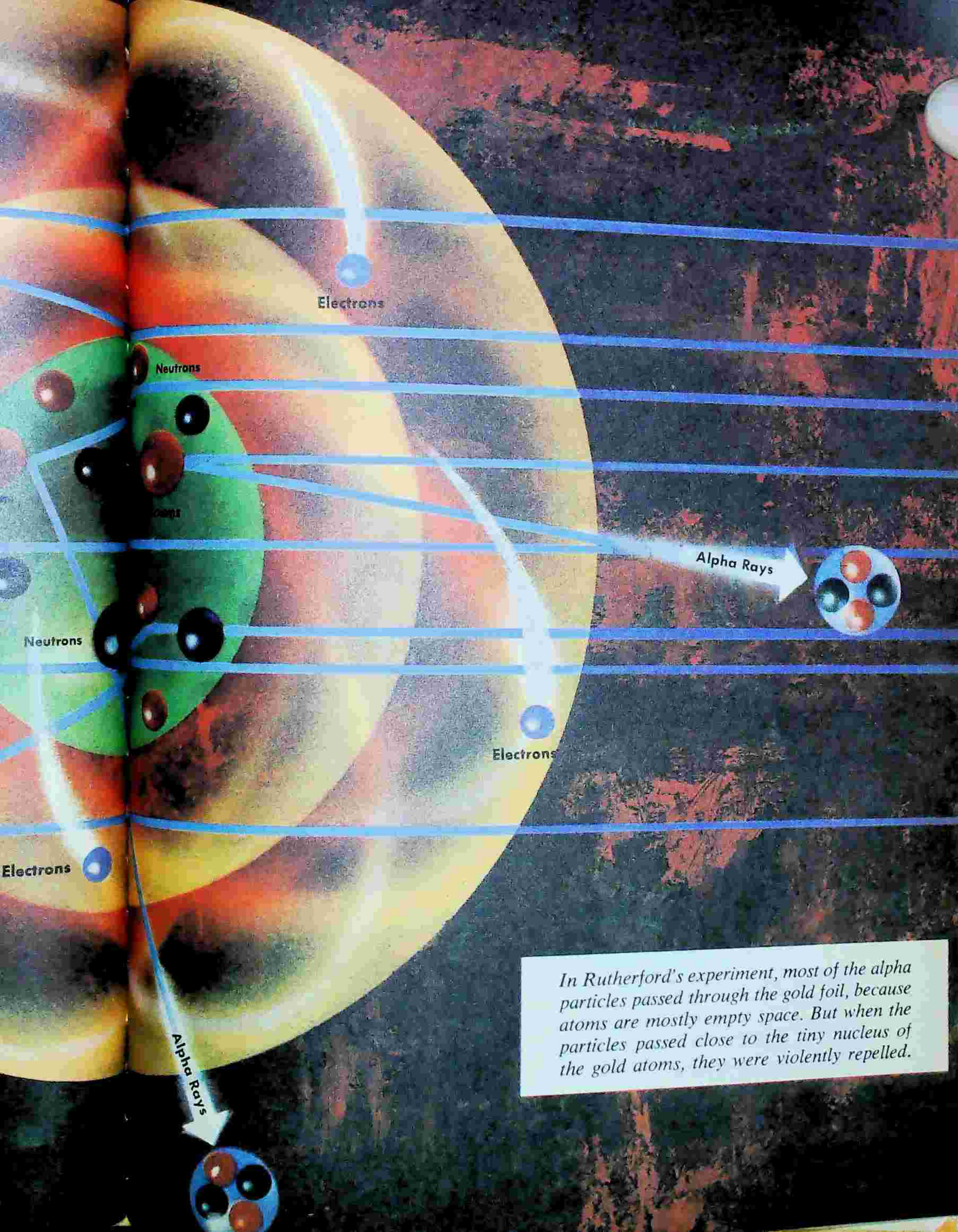


In Rutherford's experiment, most of the alpha particles passed through the gold foil, because atoms are mostly empty space. But when the particles passed close to the tiny nucleus of the gold atoms, they were violently repelled.

A ball on a string whirls outward because of its own momentum. Classical physicists believed that this same effect kept electrons from falling in on the atom's nucleus.

The Nucleus and Its Satellites

All through the history of the atom it had seemed that each new discovery raised another question. The first one raised by Rutherford's discovery was particularly mystifying: if the nucleus, the tiny solid core of the atom, was surrounded by 50,000 times as much space, why didn't all the earth's atoms collapse like so many pricked balloons?

Another question was equally perplexing. If the atom contained a positively charged nucleus and a negatively charged electron, how were they kept apart? Positive and negative charges attract each other, and in a space as small as an atom's, it was astonishing that the electron and nucleus didn't clap together with great force.

Classical physicists had speculated that as an electron and a nucleus are attracted by each other's electrical charge, so the earth and the sun are attracted to each other by the force of gravity. The electron must move in an orbit about the nucleus just as the earth moves about the sun. The earth, held by gravity, whirls around the sun like a rock on the end of a string. The momentum of the moving object (either a rock or the earth), keeps the object out in space. In the same manner the momentum of the whirling electron should keep it from falling into the nucleus. But in 1913, the Danish scientist Niels Bohr came up with a profound discovery.

The classical theory, he said, may work in certain areas, but not necessarily as regards atomic physics, because the conditions there are very different. The electrons in an atom do whirl about the nucleus in much the same way as the planets orbit about the sun. But when an electron orbits, the acceleration makes it give off radiant energy. This energy loss means that the electron also loses the momentum which it must have to make it continue to orbit around the nucleus.

Therefore, if the classical theory was right, the electron would crash! Bohr realized this, and added a startling new concept. An electron, he said, does not radiate continually; rather, it emits bits of energy (or quanta) in spurts. And it only does this when it is stimulated and made to jump from its own orbit to another one. When the electron automatically drops back in place, it releases the energy it had just gained. The electron thus absorbs and retains a sufficient amount of energy to keep it whirling around the nucleus.

Electrons (top) whirl so fast and in so many directions (center) that the electrical field that they create appears to form a solid object (bottom).

At Last: What Everything Is Made Of

And now the scientists began to pick apart the incredibly tiny atomic nucleus. Just imagine what was involved in this effort: the researchers were attempting to figure out the construction of a substance only 1/5,000,000,000,000 inch across—one five millionth of of a millionth of an inch!

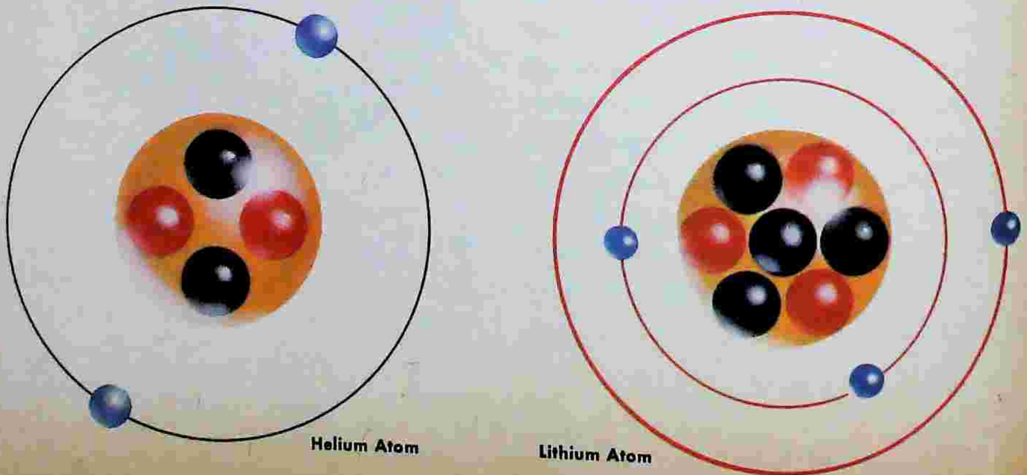
A hundred years or so before, a man named William Prout had made a suggestion about the composition of atoms which was ignored. He had said that the atoms of all the elements seemed to be made of hydrogen atoms —in other words, that hydrogen was the basic unit from which everything else was made.

Now scientists began noticing a fascinating thing about hydrogen. This element had the simplest of all atoms—just a nucleus with one electron whizzing around it. As the scientist experimented with other kinds of atoms, they began to find this hydrogen nucleus turning up everywhere. Were *all* atoms made partly of the hydrogen nuclei?

William Prout's guess had been correct. Further experimentation proved that the hydrogen nucleus could be thought of as a built-in part of the nucleus of every other atom—oxygen, gold, antimony, and so on. Scientists then named the hydrogen nucleus the "proton."

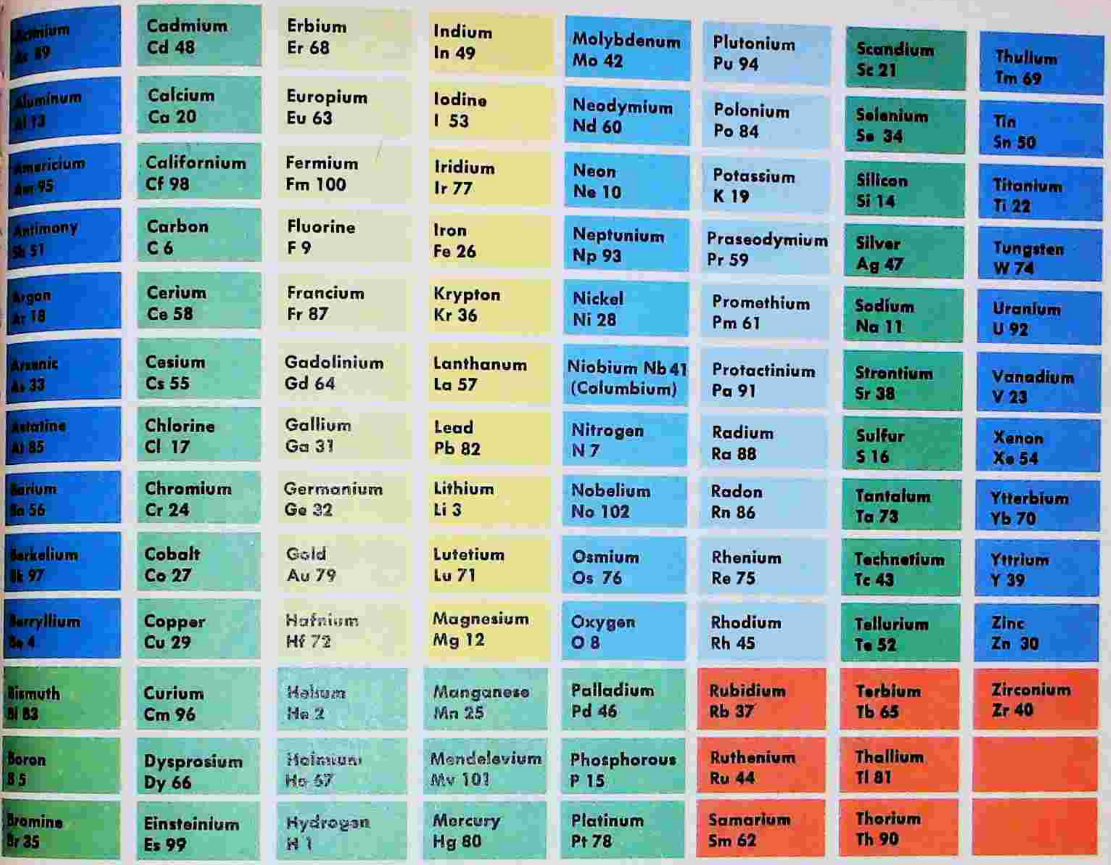
The proton, they soon learned, was heavy. In the hydrogen atom its weight was practically the entire weight of the atom, for the electron, the only other part of the hydrogen atom, weighs almost nothing. In the periodic table, or chart of elements, scientists list both *number* and *weight* after each element. The *number* refers to the number of protons in the atom's nucleus. The *weight* is the relative weight of one atom of the element compared to an atom of oxygen, if oxygen is taken as 16. The atomic weight of

All atoms contain hydrogen nuclei, or protons (black). Neutrons here are shown in red.



Helium Atom

Lithium Atom



Actinium Ac 89
Aluminum Al 13
Americium Am 95
Antimony Sb 51
Argon Ar 18
Arsenic As 33
Astatine At 85
Barium Ba 56
Berkelium Bk 97
Berryllium Be 4
Bismuth Bi 83
Boron B 5
Bromine Br 35
Cadmium Cd 48
Calcium Ca 20
Californium Cf 98
Carbon C 6
Cerium Ce 58
Cesium Cs 55
Chlorine Cl 17
Chromium Cr 24
Cobalt Co 27
Copper Cu 29
Curium Cm 96
Dysprosium Dy 66
Einsteinium Es 99
Erbium Er 68
Europium Eu 63
Fermium Fm 100
Fluorine F 9
Francium Fr 87
Gadolinium Gd 64
Gallium Ga 31
Germanium Ge 32
Gold Au 79
Hafnium Hf 72
Helium He 2
Holmium Ho 67
Hydrogen H 1
Indium In 49
Iodine I 53
Iridium Ir 77
Iron Fe 26
Krypton Kr 36
Lanthanum La 57
Lead Pb 82
Lithium Li 3
Lutetium Lu 71
Magnesium Mg 12
Manganese Mn 25
Mendelevium Mv 101
Mercury Hg 80
Molybdenum Mo 42
Neodymium Nd 60
Neon Ne 10
Neptunium Np 93
Nickel Ni 28
Niobium Nb 41 (Columbium)
Nitrogen N 7
Nobelium No 102
Osmium Os 76
Oxygen O 8
Palladium Pd 46
Phosphorous P 15
Platinum Pt 78
Plutonium Pu 94
Polonium Po 84
Potassium K 19
Praseodymium Pr 59
Promethium Pm 61
Protactinium Pa 91
Radium Ra 88
Radon Rn 86
Rhenium Re 75
Rhodium Rh 45
Rubidium Rb 37
Ruthenium Ru 44
Samarium Sm 62
Scandium Sc 21
Selenium Se 34
Silicon Si 14
Silver Ag 47
Sodium Na 11
Strontium Sr 38
Sulfur S 16
Tantalum Ta 73
Technetium Tc 43
Tellurium Te 52
Terbium Tb 65
Thallium Tl 81
Thorium Th 90
Thulium Tm 69
Tin Sn 50
Titanium Ti 22
Tungsten W 74
Uranium U 92
Vanadium V 23
Xenon Xe 54
Ytterbium Yb 70
Yttrium Y 39
Zinc Zn 30
Zirconium Zr 40

Elements known today are listed with their symbols and atomic numbers.

hydrogen was one—and it had one proton in its nucleus.

Furthermore, the proton was positively charged. It had to be, since the nucleus of every atom was positive, and the proton was the nucleus of the hydrogen atom. For every proton, each atom had one electron orbiting around its nucleus; thus oxygen, with 8 protons, had 8 electrons, and so on. This kept everything in perfect balance—one negative electron for every positive proton—and meant that the entire atom itself would be neither negative nor positive. Scientists had known that atoms were neither negative nor positive, but now they knew why.

And since the atom itself was neutral, there was another possibility which had been mentioned by the great Rutherford: maybe there were yet undiscovered neutral particles within the atom itself. Such a particle would easily escape all the electrical detection methods science had set up to examine the atom.

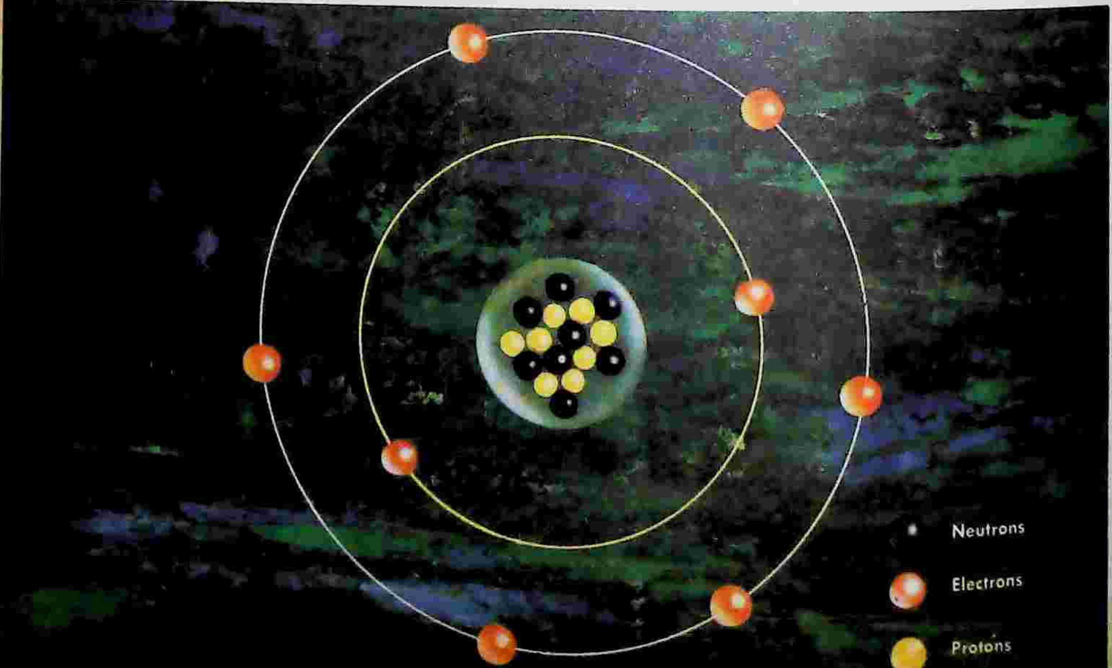
This theory was confirmed when two German physicists, Bothe and Becker, found evidence that in a collision of atoms they had arranged, a very penetrating radiation was produced. Soon many scientists were repeating the experiment and in 1932 an English physicist, Sir James Chadwick, was able to explain it. There *was* a neutral particle contained within the nucleus. The oxygen atom, to take an example, had not only 8 negative electrons and 8 positive protons–it also had 8 of the newly discovered neutral particles, which the investigators named "neutrons."

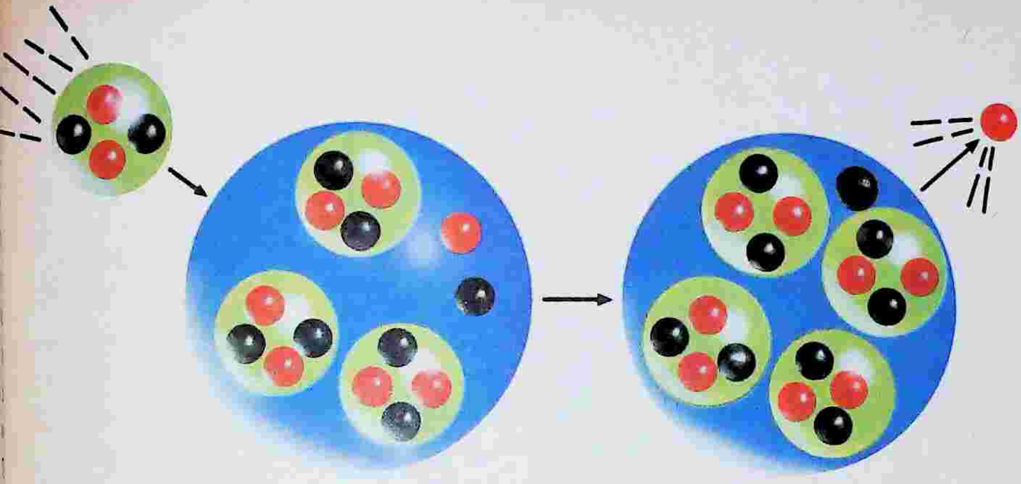
With the discovery of the neutron, science might be said to have reached the end of a long search. At last there was an answer to the age-old question: What is everything made of? Everything–wood, stone, gold, air, the human body–consisted of electrons, protons, and neutrons arranged in different combinations.

Once it had been believed that the smallest building block was the atom, and that there were a good many of these, one kind for each element, and each one different from all the others. Now the experts knew that the atom was *not* the smallest unit. Each atom, no matter how it differed from all the others, was made of electrons, protons, and neutrons. And if you could take the electrons from gold and the electrons from lead, you would find that they were exactly alike, as would be their protons and neutrons. The only difference between gold and lead was that there were more electrons, protons, and neutrons in lead than in gold.

This discovery led to a fascinating thought: if scientists could take the electrons, protons, and neutrons from lead and rearrange them in just the proper way, they could make gold–just as alchemists had once tried to do! This, in fact, has now been done.

An oxygen atom has 8 protons (yellow), 8 neutrons (black), and 8 electrons (red).





The first nuclear change was performed by Rutherford in 1919. Here, a fast alpha particle enters a nitrogen nucleus, changing it into a nucleus of oxygen, and releasing a proton.

The Neutron Breaks the Atom

Of course, the scientists of the 1920's and 1930's were not interested in making gold out of lead. It was too expensive to be worth while. Now that they knew what everything was made of, they wanted to know more about the atom and its parts.

For this, the neutron was a valuable discovery. The best way to learn new things about the atom was to shoot rays at it—which up to this time had meant shooting alpha particles and the like. But alpha particles, as we have seen, could only rarely penetrate into the most interesting part of the atom—the nucleus. The alpha particle was positively charged, and every time it came near the positively charged protons in the nucleus, it was repelled and swerved away. But why not use the neutron, that part of the nucleus which had no charge at all? It could be shot right into the nucleus, and nothing would stop it. Gamma rays are also neutral; but being a form of light, they don't have the force of a solid particle such as the neutron.

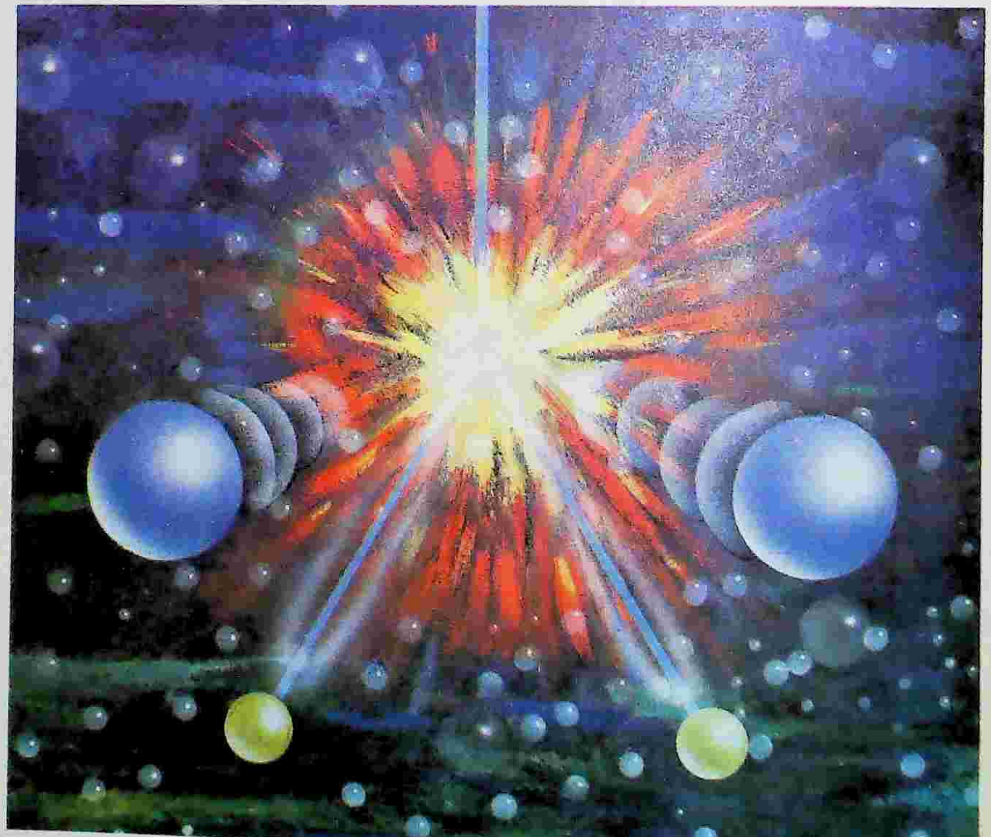
So scientists began shooting neutrons at atoms, and this time they were successful.

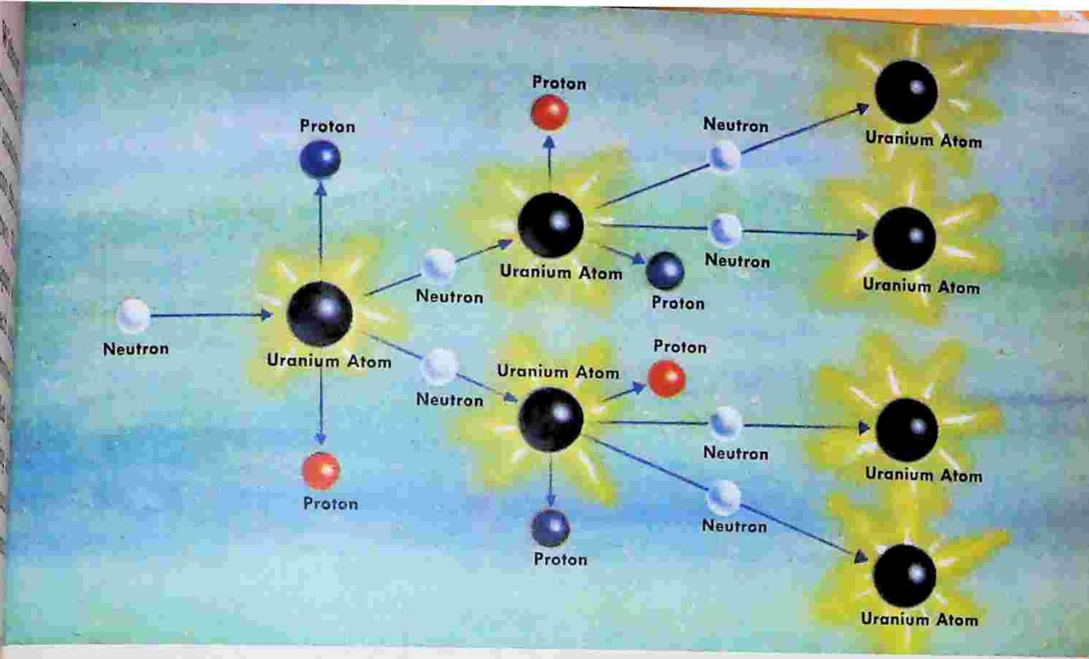
In 1938, two German scientists, Otto Hahn and Fritz Strassmann, made a baffling observation while they were shooting neutrons at uranium atoms. The atoms seemed to break in two. Instead of uranium the scientists had the elements barium and krypton. The total atomic weight was the same, but now there were two atoms where there had been one. An instrument the two men were using in the experiment indicated that a spectacular amount of energy had somehow been released—about 200,000,000 electron volts.

Hahn and Strassmann were greatly puzzled by this result and could not figure out what had happened. But a friend of Hahn's, a woman physicist named Lise Meitner, offered an explanation.

Without knowing it, Hahn and Strassmann had smashed the nucleus of a uranium atom. The neutron plowing into the uranium atom had broken it in two. The two bits of atom had flown apart with enormous force, because each contained many positively charged protons, which once separated, had repelled each other fiercely. The violent flying apart had released the energy measured by Hahn and Strassmann's instrument.

When the uranium atom split, a huge amount of energy was released.





In a chain reaction, a splitting atom releases neutrons which split more atoms.

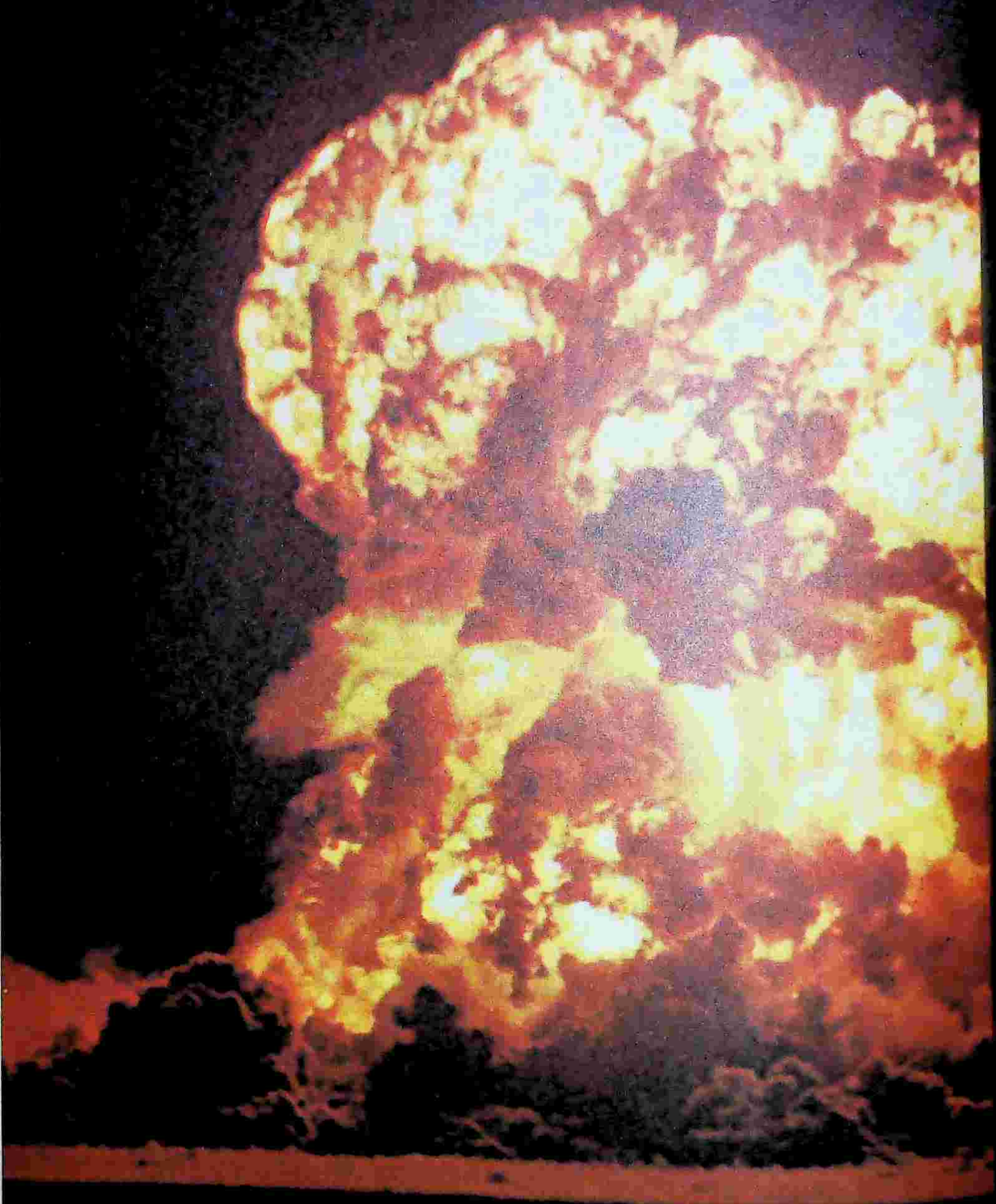
The Atomic Bomb

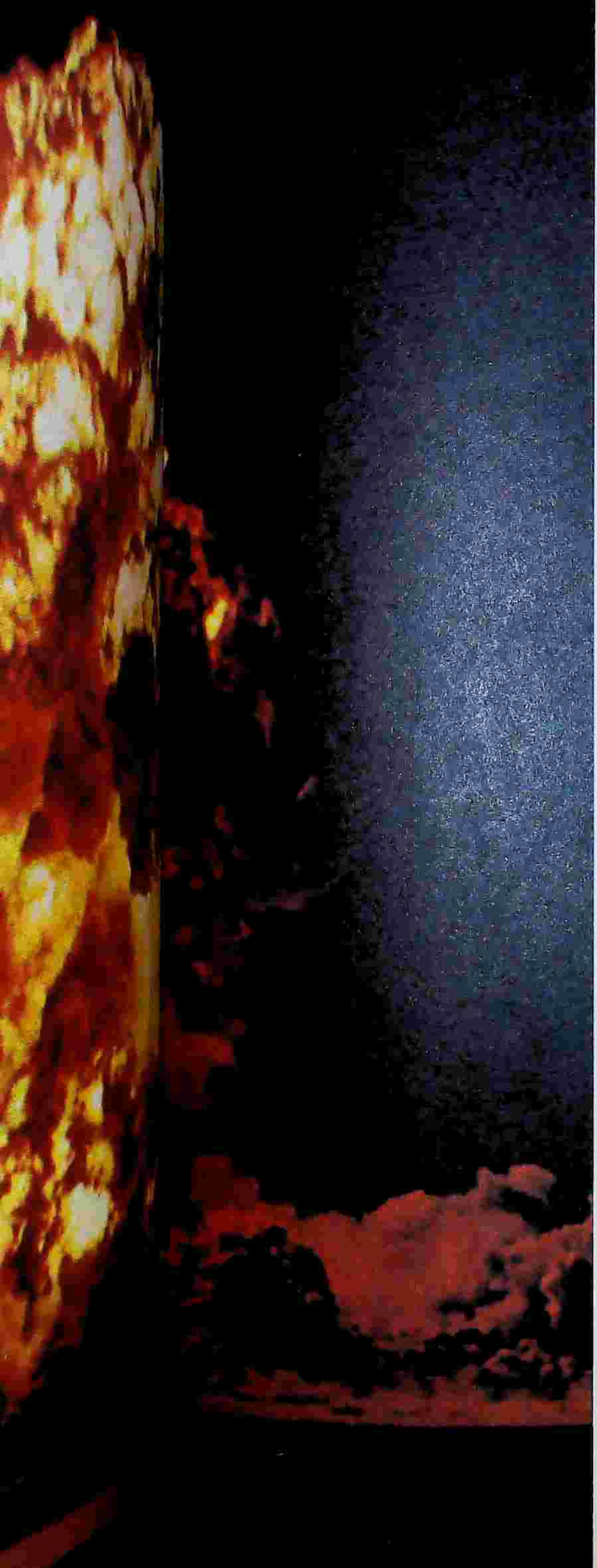
Up to the beginning of World War II, one of the wonders of the story of the atom was that scientists from all over the world had joined in the work, sharing their discoveries and rejoicing in one another's success. Beginning with the Greek Democritus, Italians, Englishmen, Frenchmen, Germans, Americans, Danes, Russians, New Zealanders, Austrians, Hungarians, Japanese, and many more had contributed to man's effort to explain the structure of the universe.

Now, science had suddenly become a weapon of war, and nations could not share their weapons with enemies. Of course, no one was really sure that a bomb could be made by exploding atoms. But if it could be done, the result would be a weapon on which would decide the outcome of the war —and every physicist in the world knew it.

The new scientific secrecy helped the United States and Great Britain. Many fine German and Italian scientists had fled to those two countries. By the early 1940's, most of them had joined with American and British scientists and many were working night and day to construct an atomic bomb.

In the fall of 1939, Albert Einstein wrote a letter to President Franklin D. Roosevelt asking him to meet with a group of scientists who had something important to tell him. When the scientists saw the President they explained about Lise Meitner's conclusions and





why they were so important: when the uranium atom had split, besides releasing great energy, it had also set loose a number of stray neutrons which had gone whizzing away like bullets. This was exciting news, for if you were to put a whole lot of uranium atoms together and split one, the neutrons it released would plow into other atoms and split them, and that would release still more neutrons to split more atoms —and on and on. The whole process, called a chain reaction, would occur in a split second and would make the biggest explosion ever known.

The scientists hated the idea of turning the atom into a fearful weapon, but they knew that if the Allied nations did not make an atomic bomb, their enemies might. President Roosevelt agreed. He ordered work started on the project immediately.

Although it was all very well to *talk* about an atomic bomb, it was quite another thing to *make* one. The main job of developing the weapon went on in the United States. It was an enormous task, and a tremendous gamble. Five years passed before the project was finished, and two billion dollars were spent. And no one could be certain whether the Allies would even get a bomb for all that money.

The material with which the scientists worked was uranium 235—an uncommon form of the element—and a

◄ *The awesome blast of an atomic bomb.*

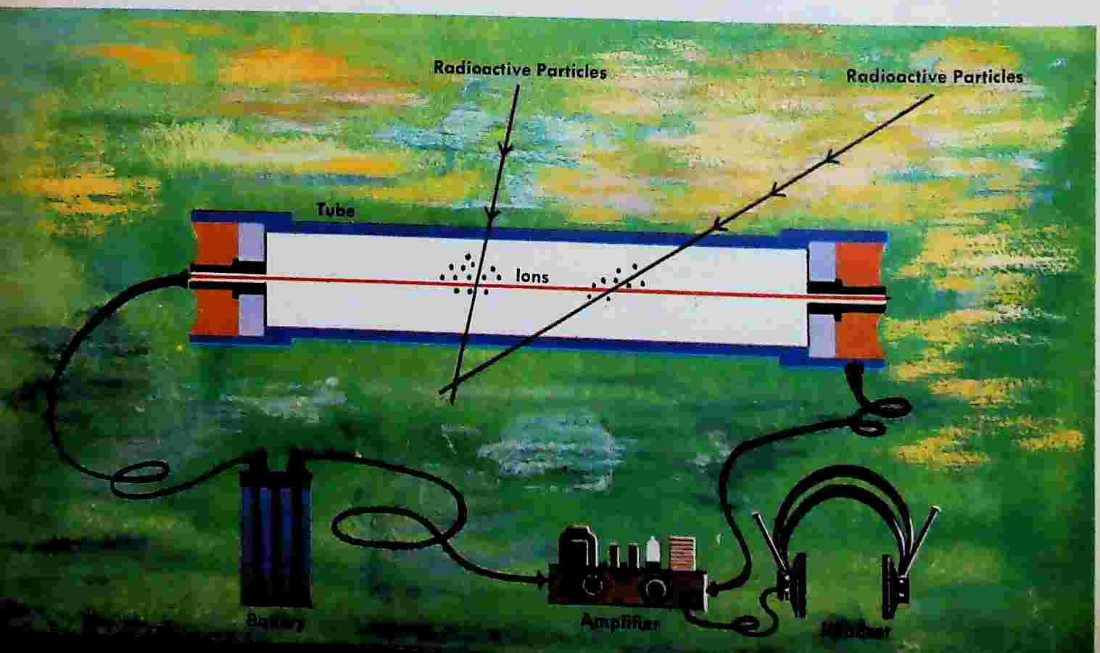
great deal more uranium was needed than had ever before been gathered in one place. Getting together a sufficient amount of uranium was only part of the problem. While uranium worked fairly well, a brand new element called plutonium could be made from uranium, and it worked even better. So great plants had to be set up to turn tons of ore into pounds of uranium, and then uranium into plutonium.

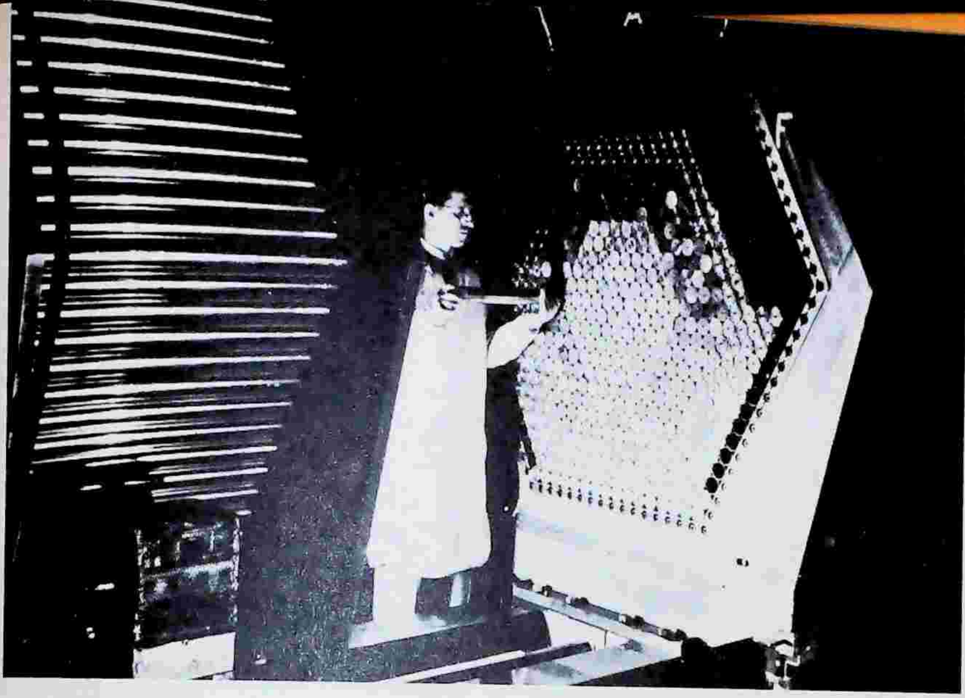
Once they had assembled their material, scientists had to find a way to put to work the atomic energy that it contained.

The great Italian scientist Enrico Fermi and his co-workers tackled the job. Like Einstein, Fermi was now living in America. In a secret laboratory under the football stadium of the University of Chicago, Fermi stacked up a large pile of carbon blocks (the carbon was in the form of graphite, the same substance that makes your pencil write black). Fermi needed carbon because it slows down neutrons; and slow neutrons are better atom-smashers than fast ones. Spaced through the blocks of carbon was just the right amount of uranium needed to start a chain reaction. (The amount was important: if there had been too little uranium there could not have been a chain reaction—the neutrons would just have gone flying off into space instead of striking and splitting new atoms of uranium.)

Pushed into this pile of carbon and uranium (it was actually called a pile—a "nuclear pile") were a number of long rods made of a substance that would catch neutrons. While the rods were pushed in the pile, too few neutrons could strike uranium atoms to set off a chain reaction. By pulling the

When radioactive particles strike a Geiger counter tube they close an electrical circuit and cause a clicking which can be heard on the headset.





Cadmium rods placed in a nuclear pile control the atomic chain reaction.

rods out slowly, Fermi hoped to control the number of neutrons striking atoms, and in that way to control the amount of atomic energy turned loose by the exploding atoms. To measure the amount of energy, Fermi had what is now a familiar instrument, a Geiger counter, which measures radioactivity by clicking every time it is struck by a gamma ray. The sound is amplified and heard through a headset.

One afternoon in December, 1942, Fermi and his associates slowly and carefully began to slide the rods out of the uranium. Tensely they listened for the reaction of the Geiger counter. Its clicking grew faster–and faster. Neutrons were pouring out of the uranium atoms, striking new atoms, causing more neutrons to pour out. A controlled chain reaction had been achieved.

All that was left now was to figure out a way to pack the right amount of uranium or plutonium into a bomb, and a way to set it off.

Building a bomb took another two and a half years. Then, on July 16, 1945, the first atomic bomb exploded in the New Mexico desert. When the awesome mushroom cloud had settled, a great hole had been scooped out of the desert.

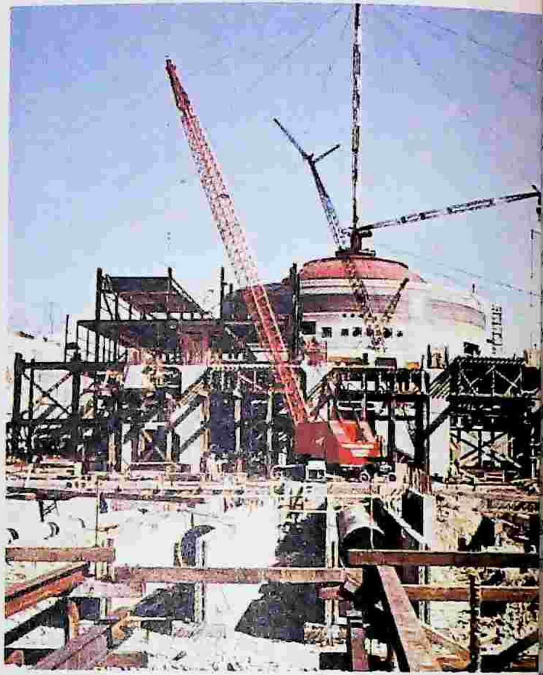
Three weeks later, the second bomb was dropped from an airplane over Hiroshima, Japan, exploding with a power equal to that of 20,000 tons of dynamite. It destroyed the entire city. Three days after that on August 9, an even more powerful bomb burst over the city of Nagasaki. On August 14, Japan announced her surrender, and the war was over.

The Wonderful Atomic Future

It has now been many years since the dawn of the nuclear age. Science has found ways to make even bigger bombs; but of even greater importance are the peacetime uses which are being found for the atom and its nucleus. People everywhere hope that atoms will never again be used for destruction. But it is certain that they will be used for constructive purposes. In fact, they already are being put to such good use by U. S. industry that in 1958 alone they brought about savings of $500,000,000. Four years of such savings are equal to the original expense of the atomic program.

Industry is not the only user of atomic energy. It is proving of tremendous importance in medicine, in farming, in transportation, in mining, in every one of man's endeavors.

Some of the more spectacular uses are well-known. Atomic plants are supplying a few cities with electricity. Atomic radiation is being used to detect some kinds of illness and to heal other kinds. Nuclear engines are propelling ships, and may soon be propelling airplanes. Someday the atom may heat whole cities, power space ships, blow up mountains, dig canals, and uncover rich supplies of minerals. Perhaps it may even be used to improve the world's climate.

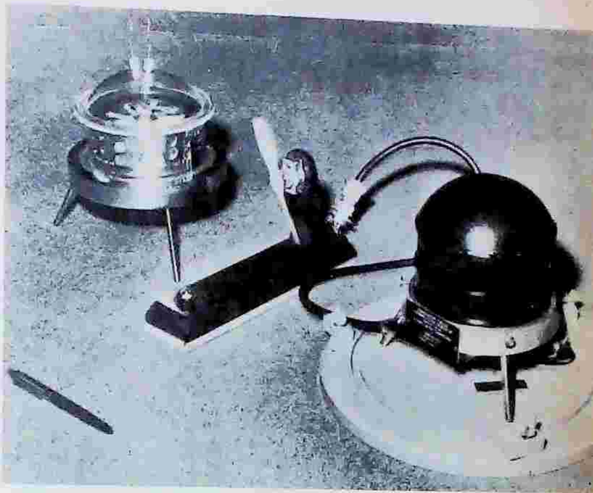


An atomic power plant in New York.

But for each of these big and much discussed projects, there are probably hundreds of lesser-known atomic applications. The atomic reactor permits us to make all kinds of elements radioactive and, in business and industry, it has especially proved to be valuable in surprising ways. Here are just a few of them:

In the petroleum industry, which often sends large quantities of oil hundreds of miles through pipelines, the atom has made it possible to pump two different kinds of oil through the same

Two tiny generators of atomic power. ►



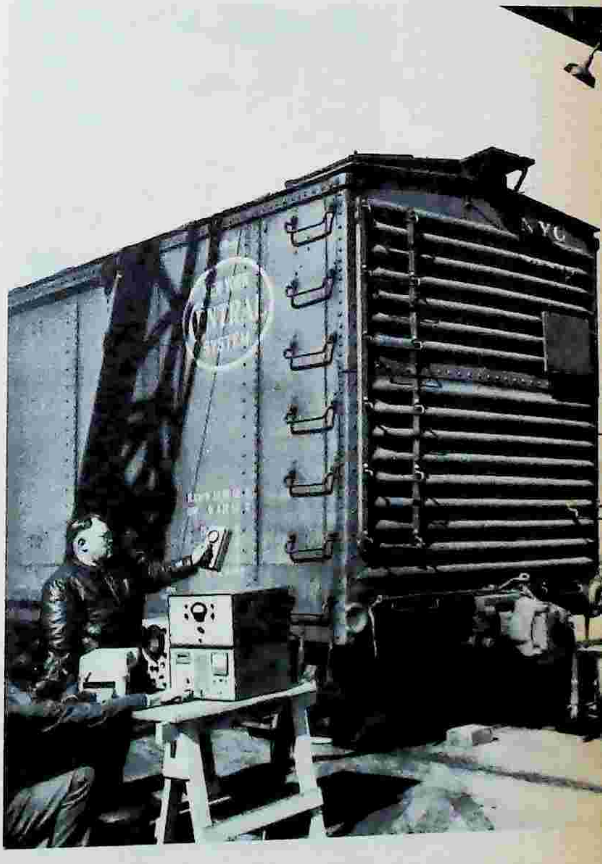
pipe, one right after another, and then separate them at the other end. Radioactive "tags" are placed between the two batches. A Geiger counter placed over the pipe at the oil's destination begins clicking when the tag passes, showing the end of the first batch and the beginning of the second.

When factory engineers want to know how fast a wheel is turning, they place a bit of radioactive material on the rim and then let a Geiger counter keep track of the number of times it whizzes past.

To measure the height of liquid stored in a closed tank, rays are aimed at the side of the tank and a counter is held at the other side. The rays cannot pass through the liquid, but at the point where the tank is empty, the counter starts clicking.

Radioactivity protects workers who must use their hands near dangerous machines. A dab of radioactive material is placed on a band around the worker's wrist. When his hand gets too close to the danger spot, the rays set off a counter on the machine, sounding the alarm.

To measure the thickness of paper, or of the sheet metal for tin cans, or of many other things, the manufacturers can shoot radioactive rays through the



A carload is weighed by measuring the atomic radiation that penetrates it.

In many places, rail signals are lighted by atomic power.

Radioactive particles may be used to control a fire alarm system.

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materials and count the number of rays that emerge on the other side. When too many rays get through, the material is too thin. When too few get through, it is too thick.

When a certain kind of plastic used to cover electric wires is exposed to atomic radiation, it toughens into one of the best insulating materials known.

Where there are hidden flaws in steel girders or other expensive metal objects, radiation can be used to detect them (X-rays were formerly used, but atomic radiation is far cheaper).

Static electricity, the kind that sometimes crackles off an automobile door handle, can be highly dangerous where explosive materials are about. Atomic energy can be used to discharge this electricity before it can do any damage.

The list of industrial uses for the atom and its byproducts is almost endless. In addition to those already mentioned, the atom is used to make better airspeed indicators for airplanes, better soap and lipstick, better transparent tape, better dyes, stronger machine tools and stronger glass. It can even be used to detect smoke or probe tree trunks to see if there are too many knots to make good lumber.

In medicine, the atom does not have as many uses as it does in industry, but it may be far more important. It relieves suffering, aids surgical techniques, helps doctors tell what is wrong with some patients, and helps them to cure others. Here are only a few examples of the medical uses of atomic energy:

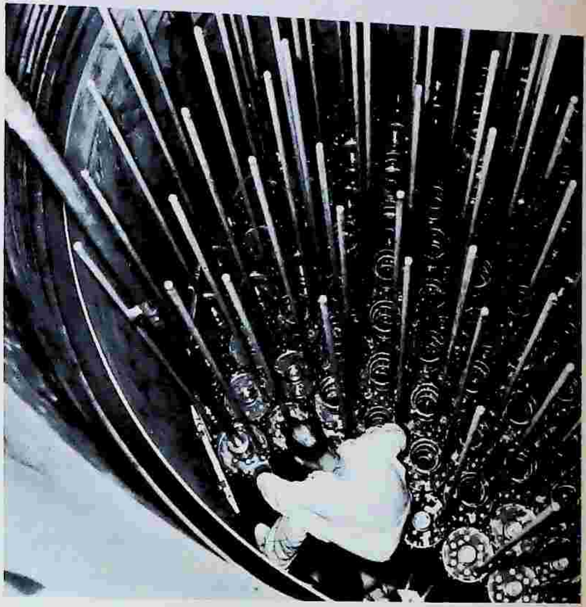
To find out what parts of the body certain medicines reach and help, small amounts of radioactive materials are added to the medicines, which can then be followed by a counter. Similar chemicals can be added to the blood, enabling doctors to tell which parts of the body are suffering from improper circulation.

As Becquerel learned to his sorrow, radioactive materials are often strong enough to burn. Sometimes these burns can be dangerous. But they may also be valuable as they can be used to destroy cancer cells which cannot be reached for surgery. Many people suffering from cancer have lived longer because of such treatment.

Hayfever sufferers will benefit from atomic research being done by botanists. In order to trace the path taken through the air by ragweed, which makes hayfever sufferers sneeze, these scientists first put radioactive chemicals into the ground in which the ragweed grows, then later follow the radioactive pollen with a Geiger counter.

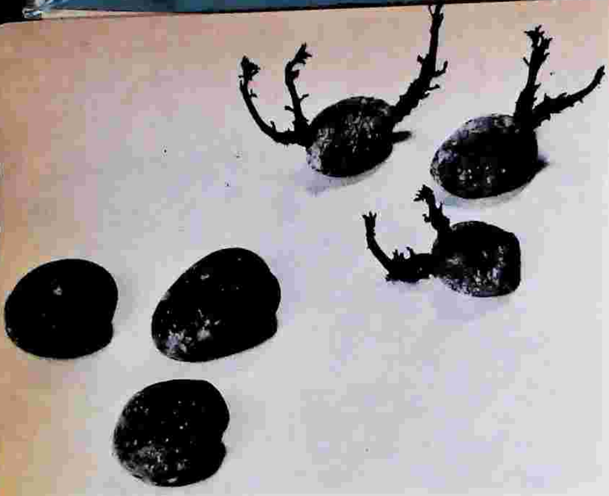
Drugs, bandages, and other medical supplies can be sterilized by exposure to atomic rays which kill germs and disease-carrying bacteria.

Insects that infest grain can be destroyed by radioactivity, saving farmers thousands of dollars. Or the early sprouting of potatoes, which makes



A worker climbs down into the interior of a nuclear reactor core.

As one man holds a Geiger counter nearby, fuel is carefully loaded into a reactor.

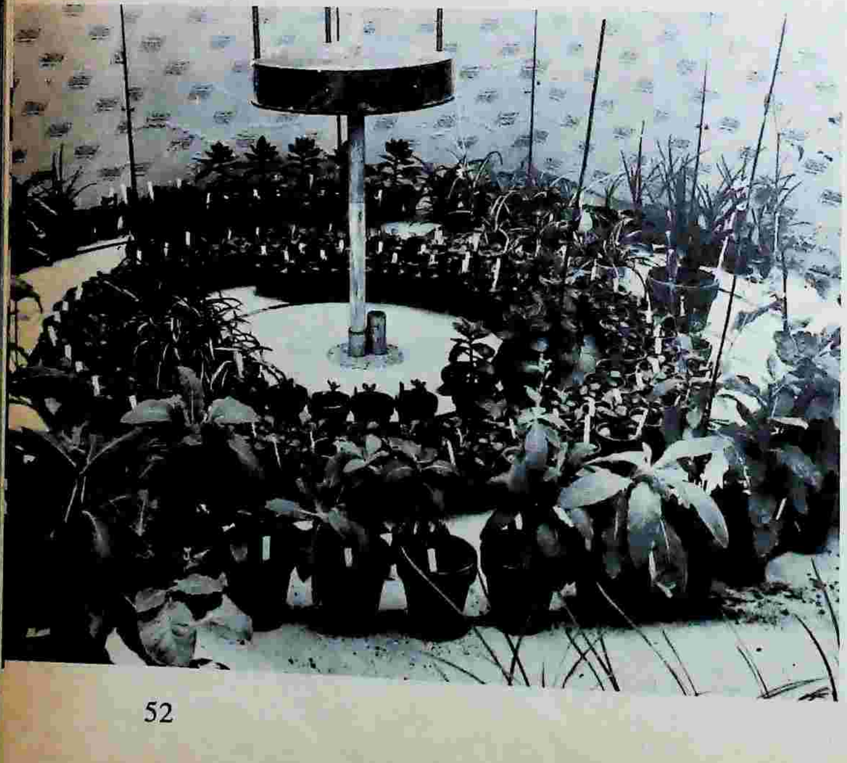


◄ *Atom-treated potatoes did not sprout.*

them spoil, can be slowed down greatly if they are treated with atomic rays.

To tell how effective fertilizers are (that is, to see which parts of a plant they reach), agricultural experts make them radioactive before spreading them on the ground. After the plants have grown up in this ground, the fertilizer in them can be traced by a counter.

The seeds of plants after radioactive exposure may produce strange growths when they are planted: big plants, twisted plants, small plants, plants with much fruit, plants without any—all have been developed in these experiments. Some varieties turn out to be much better than the original plants from which the seeds came. A new kind of peanut developed in this way, for example, produces more peanuts per plant, is able to fight off disease, and has a thicker hull.



Scientists test the effect of cobalt rays on the growth of plants.

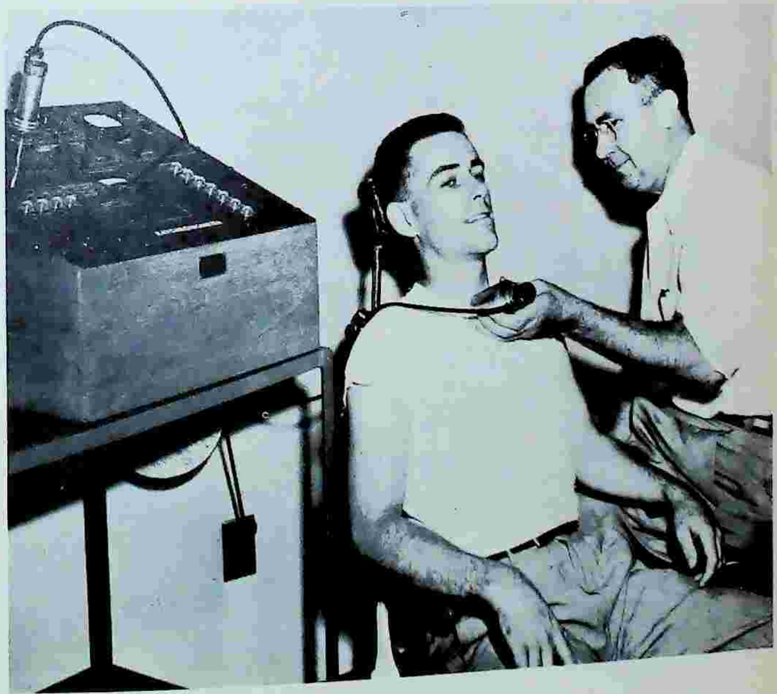
The habits of plant-killing insects can be traced by making a few of the insects radioactive, then following them with a Geiger counter to see where they go and how they live. This information is then used to develop better methods of fighting them.

And of course, there are many uses for atomic energy which are not industrial, medical, or agricultural, but are still important or interesting. For example, the bacteria which make foods spoil can be killed by radiation; foods treated this way can be sealed and kept fresh for months.

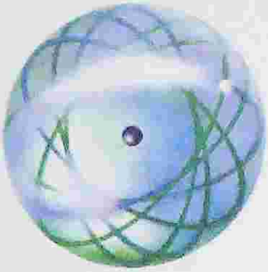
Surveyors can mark the boundaries of land with buried stakes, and then, if the stakes have small amounts of radioactive material in them, find them later with Geiger counters.

The age of ancient objects, dug up by archaeologists, can be determined by measuring the radioactivity of a kind of carbon they contain. This carbon loses its radioactivity at a rate known to scientists, and that makes it possible for them to figure out how old the object is.

In ways large and small, the atom is helping to improve the way we live. Scientists never know where their curiosity will lead them. In trying to find out what the world was made of, atomic researchers discovered a terrible weapon—but also pointed toward a better life for everyone.



After receiving a small amount of radioactive iodine, a patient has his thyroid gland examined with a Geiger counter.



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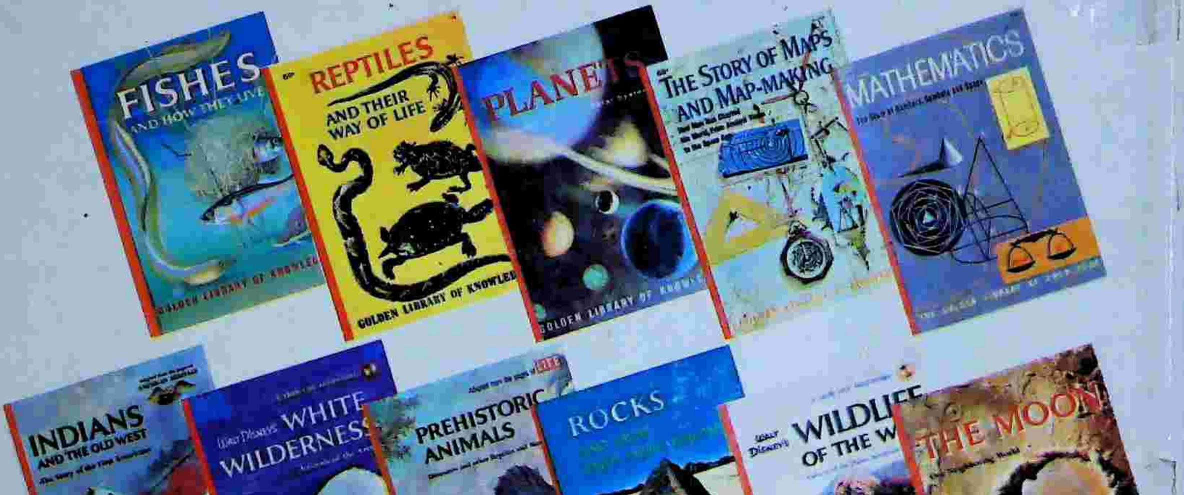

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